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HILL ROAD MANUAL

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HILL ROAD MANUAL

INTRODUCTION

- India has a vast area in hilly regions consisting of the Himalayan region from North to North-East, the central Highlands of Aravalli, Vindhya and Satpura ranges, the Sahyadri (Western Ghats) and the Eastern Ghats. Out of 28 states and 8 union territories, 9 states are predominantly in hilly regions in North and North east, whereas 9 other states have substantial hill areas. The Himalayan region itself covers about a fifth of the country's total area and about 3000 kms. of the country's sensitive international borders lie along this region. Economic development and strategic needs have resulted in launching of massive road construction programme in the hilly regions and in the recent past the activity has increased manifold.
- These hilly regions, generally, have extremes of climatic conditions, difficult and hazardous terrain, topography and vast high altitude areas. The region is sparsely populated and basic infrastructural facilitates available in more developed plains of hinterland are mostly absent. The areas and, therefore, the road are affected by floods consequent to torrential rainfall, land-slide, snowfall, avalanches etc., compelling certain roads to be kept closed in part of the year, especially in winter months. However, the areas are rich in natural resources, flora and fauna, and are important to launch development projects, industries, tourism etc.
- In view of the diverse problems met in the area, the necessity for revision of a manual for Hill Roads to bring in uniformity of standards and to serve as a guidelines considering development in modal technological advancement has been engaging the attention of the Indian Roads Congress for the past many years as the first manual was published in 1998. Accordingly, the task to revise the manual was taken up by the Hill Roads and Tunnels Committee (H-10) during the tenure 2021-23.The draft Manual was discussed in various meetings of H-10 Committee and was finalized in its meeting hell on 09.09.2022.

The Committee (composition given below) deliberated on various aspects of the manual.

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The revised draft document was placed before the Highways Specifications and Standards Committee (HSS) in its meeting held on 24.09.2022. The HSS Committee approved this draft revision subject to suitably incorporating written and verbal comments received and also recommended it for placing before the meetings of Executive Committee (EC) and Council. The EC in its meeting held on 07.10.2022 approved the draft revision for placing before the Council. The 223rd Council in its meeting held on 8th October, 2022 at Lucknow (Uttar Pradesh) considered and approved draft revision of IRC:SP:48 "Hill Roads Manual" for printing.

SCOPE

The manual deals with the various aspects of planning, design, construction, slope stability (investigation, analysis and mitigation measures) and maintenance of roads in Hilly Region. The text dealing with planning alignment survey for route selection including reconnaissance & preliminary surveys etc. and geometric design of the new/existing alignment has been dealt separately in **IRC:52 "Guidelines for the Alignment Survey and Geometric Design of Hill Roads"**

The guidelines contained in the Manual have largely been drawn from relevant IRC/IS codes, Ministry of Surface Transport Specifications for Road and Bridges Works, DGBR Technical, IS codes and other similar publications. To make the guidelines exhaustive, the standard practices prevailing in different Departments, Research/Technical Institutions have also been included in the Manual. The Manual, based on codes, practices etc., as per standard engineering norms, has been complied using the experience and expertise of the members of the Hill Road Committee and Engineers who participated and contributed to the deliberations and discussion of the chapters in the Hill Road Committee meetings.

The guidelines contained in the Manual will apply to all phases of construction and maintenance of hill roads. Where the guidelines are silent, the relevant IRC codes, Ministry of Surface Transport Specification and/or IS codes, such as IRC:SP:106, IRC:HRB SR:15, IRC:75, IRC:SP:63, IRC:52 would apply. Considering the vast variations in terrain, climatic and topographic conditions in the different hill region of the country, an uniform system cannot obviously, apply to all areas. As such, the guidelines in the manual relevant to the areas have to be applied. The experience and feedback from the engineers on adoption of the guidelines in the manual will enable upgradation and updation of the same.

1. ALIGNMENT AND FORMATION WORKS

1.1 General

1.1.1 Before taking up formation work, alignment of the hill roads shall be finalized. For the subject matter relating to Planning, Alignment survey for route selection and Geometric design of alignment, **IRC:52 "Guidelines for the Alignment Survey and Geometric Design of Hill Roads"** shall be referred. Formation is the finished profile of the road, ready for construction of protective/drainage works, carriageway/pavement, shoulders, drains, parapets etc. Some typical sections of formation in different terrains are shown in bring here **Fig. 1.1**.

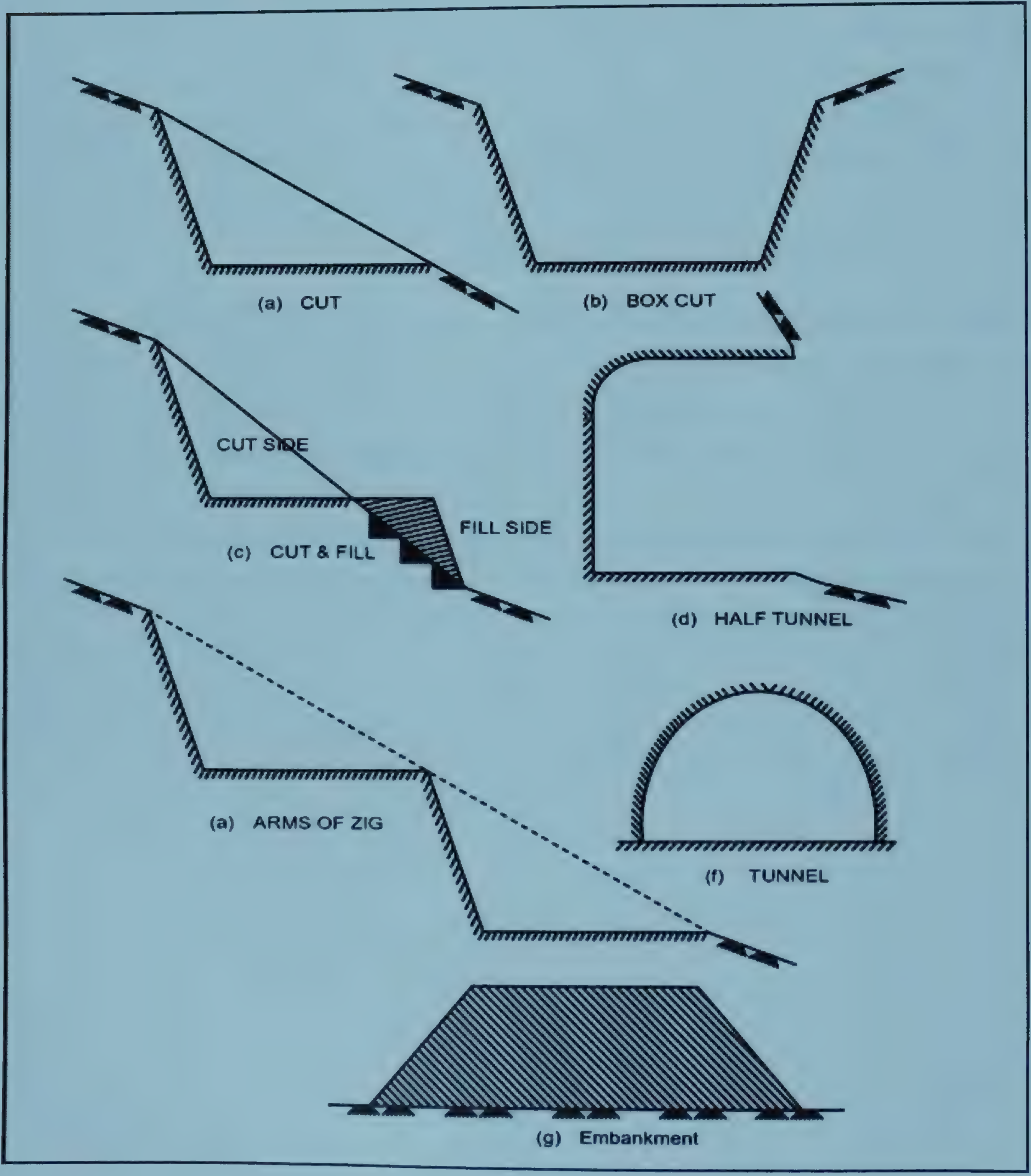

(a) CUT
(b) BOX CUT
CUT SIDE
FILL SIDE
(c) CUT & FILL
(d) HALF TUNNEL
(a) ARMS OF ZIG
(f) TUNNEL
(g) Embankment

Fig. 1.1 Typical Sections of Formation

1.1.2 Construction of formation on hill roads generally comprises of the following items of works:

a) Jungle clearance including clearing of under-growth, brush wood, shrubs, creepers and cutting down of trees.

b) Earthwork in excavation in ordinary soil, soft rock and hard rock or soil mixed with boulders.

c) Earthwork in embankment with suitable material including protection of slopes.

d) Temporary expedients during initial construction like temporary side/cross drains, dry stone/bally revetments, service soling/shingling in weak soils to keep the road traffic worthy (mainly for construction/supervision traffic) till proper structures and pavement are constructed.

1.1.3 On the finalized alignment, construction of formation is taken up with reference to the trace-cut made along the selected alignment. Various aspects of construction of formation, including the trace-cut, are brought out in the succeeding paragraphs.

1.2 Trace-cut

1.2.1 The subject of Trace-cut has been dealt in **IRC:52**. This is a primary operation for formation work.

1.2.2 The trace-cut provides an inspection path for inspection of the alignment by the inspecting officers. It facilitates detailed survey (like levelling, plane table/compass surveys) of the alignment for preparation of detailed estimates for the works. It also serves as approach track for the formation cut construction parties deployed forward ahead of the main construction party. Trace-cut also helps in determination of the classification of soil close to the actual one likely to be encountered in the formation cut.

1.3 Jungle Clearance

1.3.1 The alignment of hill road generally passes through dense vegetation except for barren snow clad areas and cultivated habitations. The land is either Government (forest/revenue) or privately owned or in some areas owned by village. Clearance of vegetation/jungle along the proposed alignment is the first activity in actual construction of the road. Before commencement of the work, various formalities like allotment/acquisition of land from revenue/land acquisition authorities and de-reservation of forest land from Forest Authorities under Forests (conservation) Act, 1980 shall be completed so as to obviate any complications/delays. As clearance of jungle results in reduction of green cover and is harmful to environment and ecology, and upsets eco-balance, when done on a large scale, it is essential that alignment is so chosen to minimize jungle clearance. Even when clearance is inevitable, only the barest minimum must be cleared.

1.3.2 Jungle clearance is generally done in two stages as under :

a) Clearance of undergrowth. shrubs, bushes creepers and ballies upto 30 cm girth

b) Cutting down trees exceeding 30 cm girth

1.4 Earthwork-Excavation

1.4.1 The earthwork for formation of the hill road involves mostly side-cut excavation to achieve designed formation width. For the purpose of excavation the soil is classified in three broad categories as under.

a) Ordinary/Heavy Soil: This comprises of organic soil, clay, sand, moorum and stiff clay which can be excavated manually by pick axes and/or shovels or with excavators with normal efforts. This can be cut to side slopes of 1:1 to 1/2:1 (H:V). Soil mixed with boulders is also deemed to come under this category.

b) Ordinary/Soft Rock: This comprises of soft varieties of rocks such as lime stone, sand stone, laterite, conglomerate ,other disintegrated/weathered rocks or predominantly with loose boulders, which can be excavated by crow bars and/or pick axes and or mechanical excavators without blasting or with casual blasting of trapped hard mass within the soft rock. Except disintegrated/ weathered rocks and predominantly loose boulders, this can be cut to side slope of 1/4:1 to 1/8:1(H:V). In respect of disintegrated rocks and predominantly loose boulders which can be excavated by crow bars and/or pick axes and/or mechanical excavators without blasting, the side slopes has to be designed as per slope stability requirement depending upon the available cohesion and other physical parameters of the disintegrated mass and its tendency to continuous sliding by itself under its own weight, even over the provided slope protection works/ slope stability measures.

c) Hard Rock: This covers any hard rock, excavation of which involves intensive drilling and blasting. This can stand vertical or even overhanging cut depending on the type/mass and dip of rock. Normally the cut may vary from 80^0 - 90^0 to horizontal.

Note: Classification of earthwork is at times done based on tools of excavation viz spade-work, pick work, jumper work and blasting, which also more or less corresponds to the above classification.

Measurement and payments for formation cutting should be done on unit price basis based on excavated quantity. In order to ensure proper calculation of quantity reference levels before start of excavation must be noted and subsequently the excavated quantity must be based on L-Sections and X-sections of the final excavated surface. This is an important aspect in hills as actual quantity of excavation is difficult to be properly estimated before actual execution.

1.4.2 The excavation for formation cut follows the jungle clearance with appropriate distance lag. The excavation is done manually or mechanically using angle excavators (Tracked excavators with angle dozing blades) based on various relevant factors. If done manually, the work is commenced generally from the top edge of the cut working downwards. If done by mechanical means, the work is commenced generally using excavators, and started at trace-cut level cutting sideways into the hill side. The work can be done either in one operation or in two stages i.e. construction of a 2.5 m wide track in first stage and widening it to designed width in second stage. While single stage construction obviates redeployment of resources in the same stretch, the two-stage construction is preferred where there is an urgent requirement to establish some sort of early communication at least for light vehicles, initially.

1.4.3 The choice of manual/mechanized cutting and single/two-stage construction has to be made on detailed examination in individual cases depending on various individual factors, viz terrain, availability of manpower and machinery, workability, time constraints and cost aspect. However, a combination of manual and mechanical cutting (with about 25 to 30% work being done manually and 70 to 75% work being done mechanically) and single stage construction is most suitable for construction of hill roads under normal circumstances. However, as excavator can operate only on about 2.5 m width at a time, the construction operation must be initial cut by forward excavators followed by widening to final width by rear excavators. Typical deployment of excavators is given in **Fig.1.2** However, two stage cutting has the advantage that a road of adequate width becomes available after first stage cut itself for equipment/machines to move and also to undertake work from forward road heads to which machines and stores can be easily moved.

1.4.4 In order to achieve maximum output, the excavator shall be deployed to work downhill assisted by gravity to enable greater loads to be pushed. When the starting point of the road sector is at lower altitude, the excavator may be moved to higher location by cross country move or by making approach track along the trace-cut to minimum essential width for movement of excavator and then start working downhill from that point backwards. The blade of the excavator is used as angle blade for side hill cutting with the leading edge of the blade towards the hill and tilted downwards so as to get maximum bowl fill of the blade.

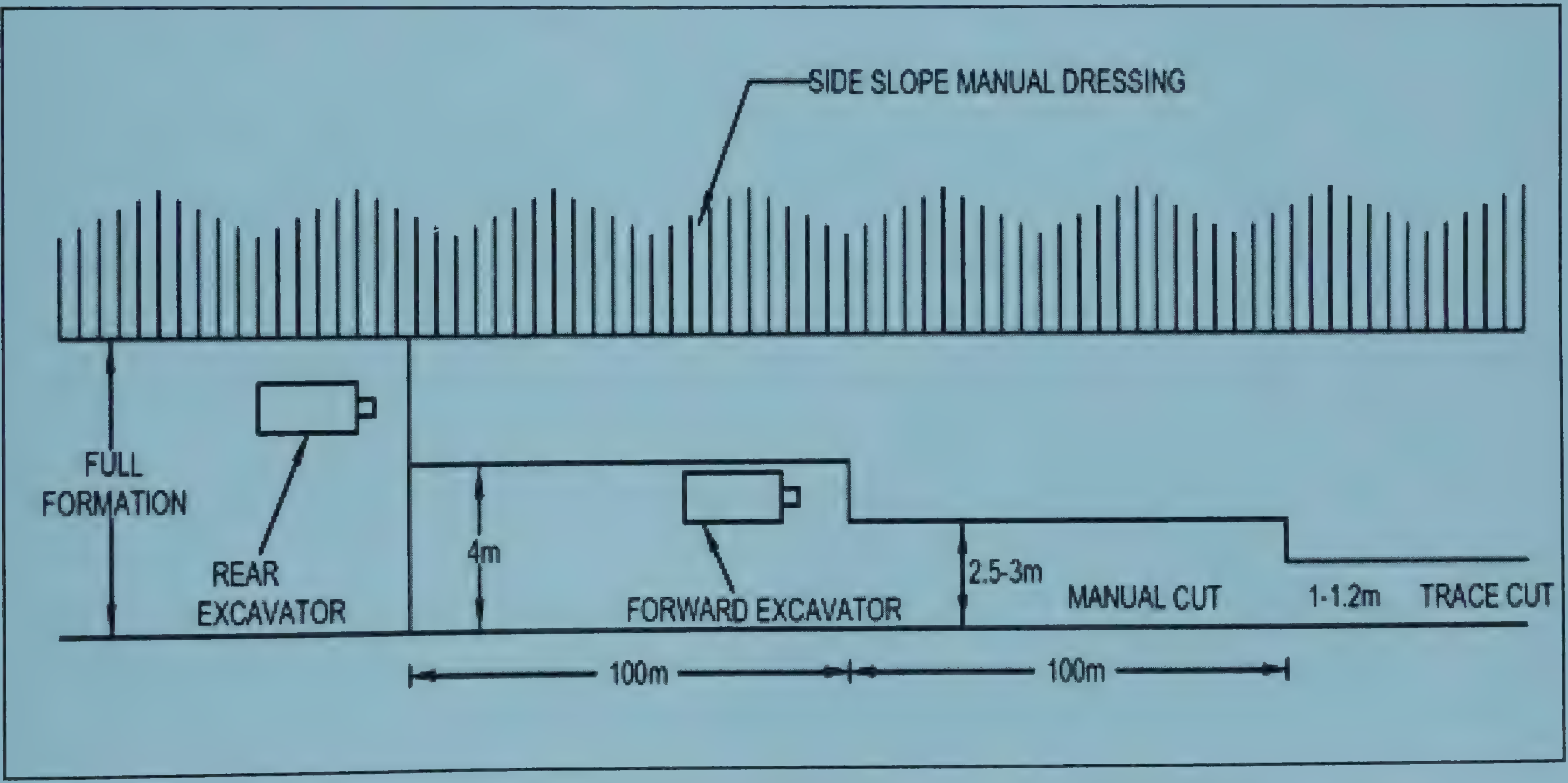


Fig. 1.2 Typical Deployment of Excavation Machinary for Formation Width

1.4.5 The rate of progress in ordinary soil is much faster than in rocky areas/disintegrated loose rock/ loose boulders/ slide zone. As a result, at times the progress gets hampered when rock /disintegrated loose rock/ loose boulders/ slide zone is met with and earthwork resources remain Idle. To avoid such a situation, the Officer-in-charge shall inspect the trace-cut well ahead of the construction party and if any isolated bottlenecks like rocky /disintegrated loose rock/ loose boulders/ slide zone stretches or bridge sites are encountered, the work on these bottlenecks shall be commenced by sending working parties well in advance, so that the bottleneck is cleared by the time main working party reaches that location. The trace-cut can be used as approach track for such parties or initial formation cut with minimum width to move compressor/excavator shall be made, if necessary. It is often possible to take excavator to forward location cross-country and commence work from that road-head also to overcome delays due to intermediary rocky / disintegrated loose rock/ loose boulders/ slide zone stretches, etc., to accelerate progress.

1.5 Rock Cutting

1.5.1 Rock cutting involves drilling with specialist equipment, blasting with explosives and the clearance of blasted debris with excavator. These, being very expensive and risky operations, call for thoughtful planning and careful execution by personnel having thorough knowledge and extensive practical experience in rock cutting work and use of drilling and blasting equipment and explosives. Apart from the immediate cost and risk, improper/excessive use of explosives may result in large scale disturbance of hill side creating slide areas leading to erosion and expensive control measures.

1.5.2 There is a wide choice of drilling equipment, compressors, explosives and accessories. Selection of these items may be made after careful assessment of job requirements and technical data supplied by the manufacturers of various products. All statutory laws, rules and regulations pertaining to procurement, transportation, storage, handling and accounting of explosives shall be strictly followed. However, this being an essential operation of formation work, important aspects related to formation work are given here.

1.5.3 The planning of rock cutting work comprises of:

a) Determination of resources/stores required based on estimated quantum of work, output norms and target time for completion of the work.

b) Location of most advantageous points/faces to commence the work based on detailed ground reconnaissance.

c) Working out the drilling pattern most suitable to the particular location, assessing the quantum of individual charge and sequence of blasting.

d) Special precautions for wet/under-water/cold weather blasting and dealing with misfires.

e) The effort shall be to collect and store as much blasted rock and stone boulders as possible to use the same for subsequent protective, drainage and pavement works.

1.5.3.1 Drilling and Blasting

Drilling and Blasting both require a thorough analysis of the rock strata based on which drilling pattern, charging of holes, quantity of explosives to be used and safety arrangements of the operation is to be planned. The subject of rock cutting, and related blasting techniques are dealt with extensively in **Chapter-12 “Rock Blasting’**.

1.5.3.2 *Clearing*

After blasting, sufficient time shall be allowed to elapse to allow for any loose stone to fall. The site is inspected for any dangerous overhang or loose stone. These are removed carefully to avoid accidents. The clearance of blasted debris is then taken up either manually or with excavator under proper supervision. During the clearing of debris, maximum possible stone shall be retrieved and stocked/shifted to suitable locations for use in protective, drainage, pavement works etc. subsequently.

1.5.4 The three operations of drilling, blasting and clearing the debris shall be synchronized in such a manner that none of the resources are allowed to remain idle. The work shall be planned at two or three adjoining locations, so that drilling and charging at one site is under progress while clearing of previous blasting at other site is being done. The deployment is reversed after blasting at the first site by which time the second site shall be ready for drilling/charging.

1.6 Embankment/Cutting/Filling

1.6.1 In hill roads, heavy embankment work is very limited. The ratio of cut and fill method can vary with the slope and terrain of hill. However, there is limited scope/requirement for adopting cut and fill method in mountainous region except at few places where valleys are to be negotiated between hill features or mountain ranges. For achieving the formation width of road partly in cut and partly in fill section, considering the stability criteria, efforts may be made so that not more than 20% of entire formation width is done in filling on valley side by conventional methods (except specialized method) of compaction duly protected with sound slope stability measures on hill as well as valley side, strictly as per structural design. The area where the embankment/fill is to come is cleared of all organic matter. Selected material for new embankment is spread and consolidated in layers with roller. In case of cut-and-fill with excavator, the consolidation is normally achieved under excavator operation. Typical cross section of Embankment/cut and fill are shown in **Fig. 1.3**.

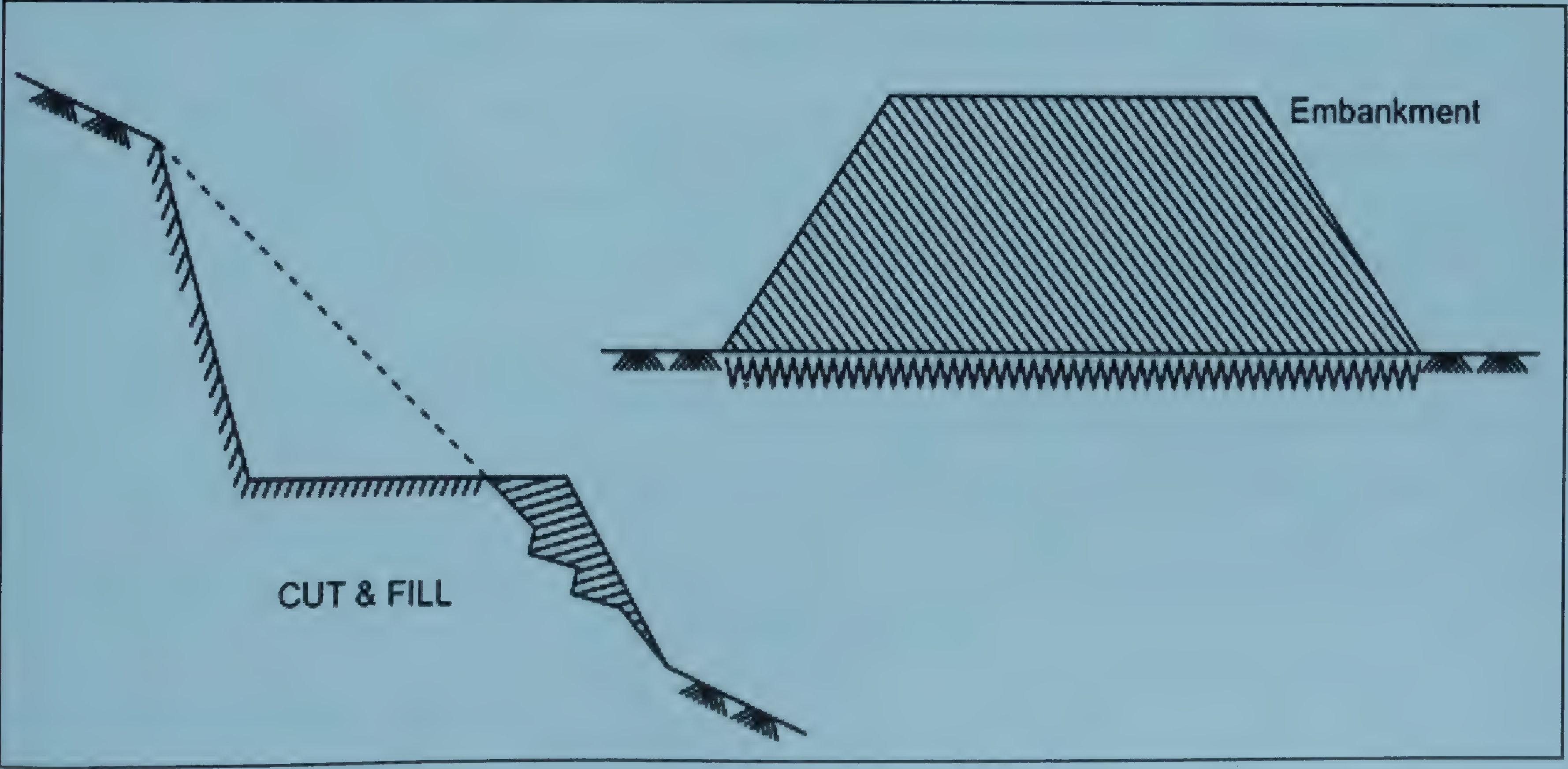


Fig. 1.3 Embankment/Cut & Fill

1.6.2 No slope on cutting as well as filling on hill/mountainous roads shall be left unprotected and shall be protected from failures in accordance with stability consideration as detailed in **Chapters 3 & 4**. The slope on cut and fill side on hills and dumping yards shall be protected from failure by constructing soundly designed structures like gabions/wired masonry crates/breast walls/retaining walls/Geo-synthetics/metal fabrics duly anchored with steel nails/ reinforced soil structures/rock fall protection measures or any other appropriate sound technology etc., with appropriate drainage arrangements of the back fill. The slopes of embankment in valleys/fill shall be protected from erosion by planting turf/grass/locally available plants besides providing soundly designed slope stability structures.

1.7 Profile Finishing

1.7.1 During the main earthwork/rock cut operation, it is not possible to achieve the final desired profile according to design gradients, super elevation, camber, side slopes etc, unless the entire work is done manually. The final finish is done in such cases, by deployment of a separate working party with a grader assisted by adequate labourers. The requirement of dressing (cut/fill) at each location is worked out by proper survey and guidelines given to grader operator/supervisor. The unevenness in the rock cut is filled up with broken pieces of appropriate size and blindage of suitable material is spread over the surface to give smooth riding. Kutcha drains made at the time of formation cutting for surface/hill side drainage are made pucca when suitable breast and retaining structures are made.

1.8 Expedients

1.8.1 Hill roads are generally constructed in areas where there are many water bodies like rivers, rivulets and nallas flowing across the alignment. During the formation work these need to be crossed by using temporary arrangements which need to be kept in place till the time permanent structures are built. These water gaps needing bridging effort should be properly measured during the trace cut and temporary bridges in form of steel bridges or any other available bridge stores should be catered in the estimates for the work. Such bridges can be recycled subsequently after permanent structures are built as solicited by the gap.

1.8.2 The estimate of formation works must also cater for soling works to keep the formation cut trafficable for induction of labor and machinery especially during rainfall and snowfall seasons. This soling may form part of sub base if it can be placed at the design level of the road. However, in most cases such soling may not be the final sub base and needs to be catered only for the construction phase of the hill road.

1.8.3 Another method of retaining the hill side can be adopted by using wire crates/Gabions placed sloping towards hill filled with stones.

“Wire crates/Gabions shall be provided as shown in **Fig 1.4** as per IRC specifications and in accordance with IS 280 & IS 4826”

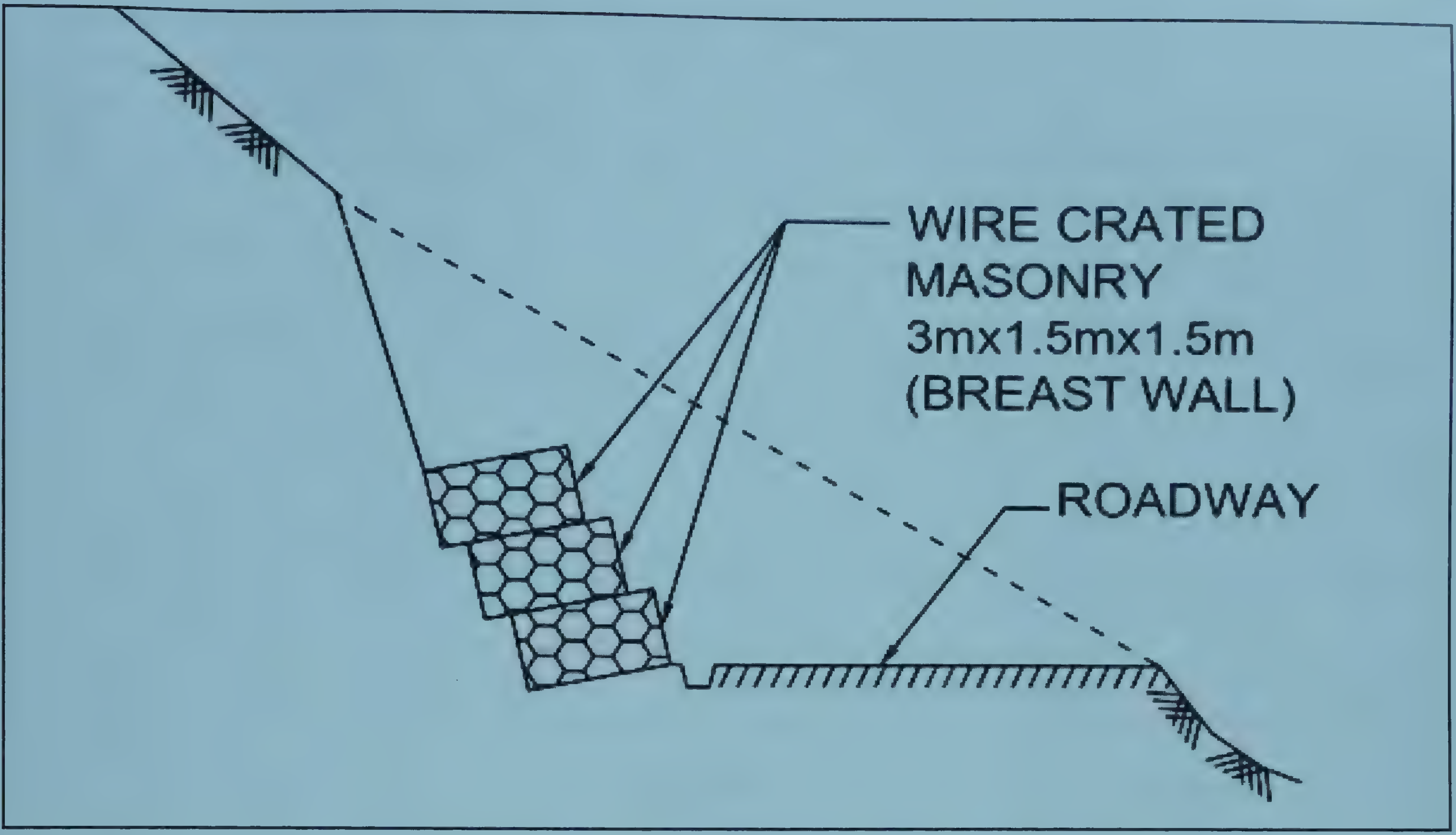

WIRE CRATED
MASONRY
3mx1.5mx1.5m
(BREAST WALL)
ROADWAY

Fig. 1.4 Typical Wire Crate Gabions with Batter Angle

1.8.4 In certain locations it may be appropriate to cut a 2 m ledge above road level to ease slope and to intercept drainage, as shown in **Fig. 1.5**

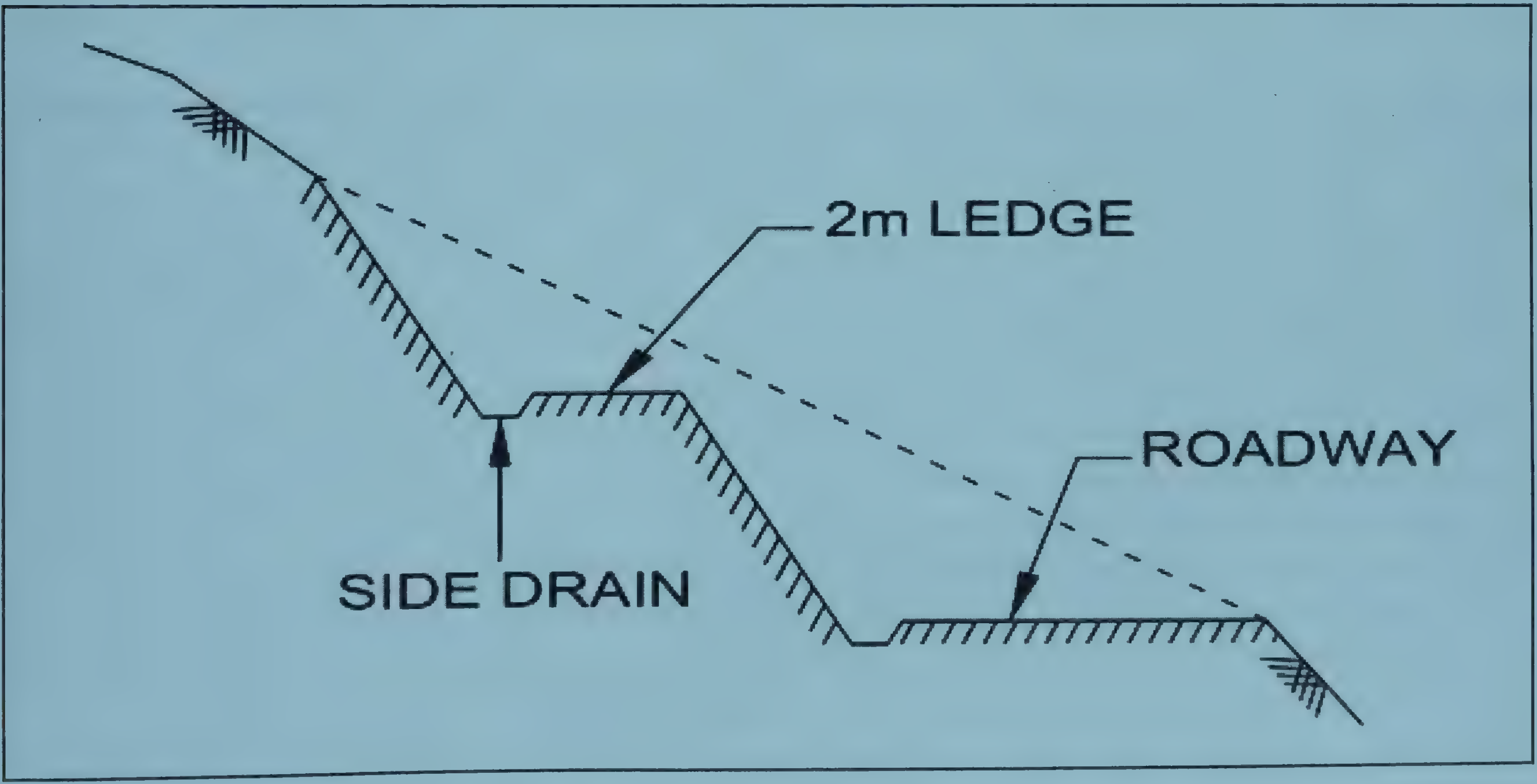

2m LEDGE
ROADWAY
SIDE DRAIN

Fig. 1.5 Ledge and Drain

1.9 Some Special Treatments

1.9.1 *Geo-synthetics/Metal Fabric Anchored with Nailing/ Reinforced Soil Structures*

Geo-synthetics which include geotextile, geogrids, geonets, geo-membranes and geo-composites can be used in various applications of road and bridge works. Metal fabric duly anchored with nailing can be used for slope stability of soft rock prone to sliding. Similarly, the reinforced soil structures can be used for construction of embankment. Some of the application areas for geo-synthetics and their functions are given in **Table 1.1**.

Table 1.1 Applications and Functions of Geo-synthetics

Sl. No.	Application Area	Geosynthetics Involved	Functions for Performance
1.	Embankments on soft soils	GT, GG	R, S
2.	Retaining Walls	GG, GT	R
3.	Drainage and Filtration	GT	F, S
4.	Drainage-prefab, composite	GC, GN	D, F, S, B
5.	Erosion Control rip rap	GT	F, S
6.	Sediment control-silt fence	GT	B, R, S
7.	Asphalt overlay	GT, GC	B, R, S

Note:		
	GT – geotextile	S – separation
	GG – geogrid	R - reinforcement
	GC – geocomposite	F - filtration
	GN – geonet	D – drainage
		B - barrier

Specifications for various applications are given in Section 700, 3100 of MORTH Specifications.

1.9.2 *Catch Water Drains*

Drains provided on hill side away from the road to intercept and divert the flow of water before it reaches the road side drain are known as catch water drains **(Fig. 1.6).** Their location, size, gradient and lining helps in checking potential slides.

1.9.3 *Box Cut*

At steep and narrow spurs, box cut or through cuts may be provided. These reduce the length of the road and also improve the radius of curves. Such cuts, however, have their own problems. During excavation, the cutting and disposal of spoils take more time and efforts as compared to hill side cut. Drainage of road surface and surrounding areas is difficult. Sub-surface springs get activated on the formation during wet weather. If the soil is unstable box cuts become trouble spots due to frequent slides and blockage of road, requiring expensive protective works, like breast walls, sub-soil drains, catch water drains etc. A careful study and comparative cost analysis of reduction in length vis-a-vis provision of additional protective works shall be made before taking a decision on providing box cuts. A typical cross section of box cut is shown in **Fig. 1.6**.

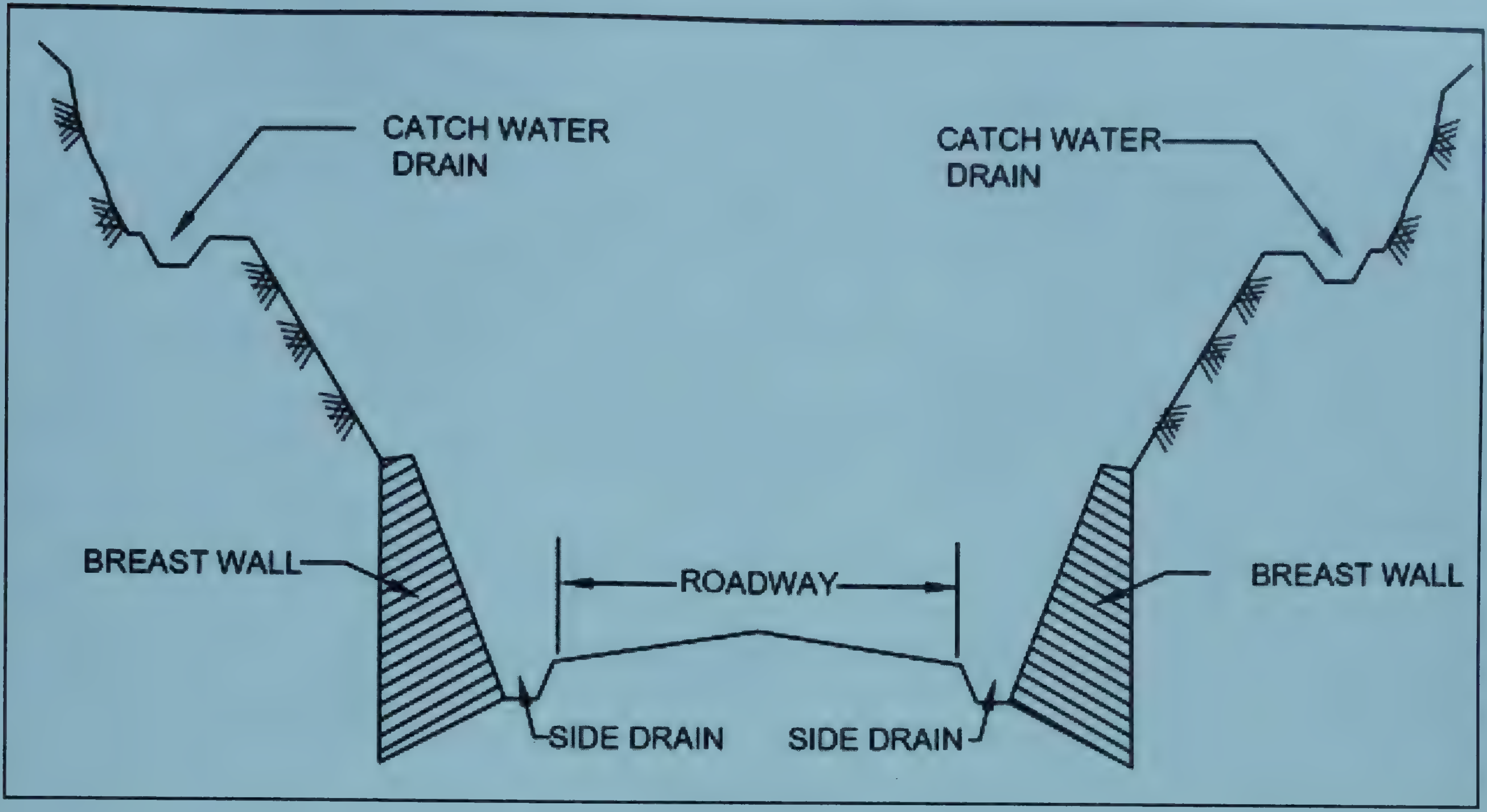


Fig. 1.6 Typical Box Cut

1.9.3.1 However, it will be good to provide a box-cut at suitable sites, not only for reduction of length, but to ensure safer road for traffic, as it eliminates possible sharp or blind curves with lesser sight distance.

1.9.4 *Dry Gap Bridge*

At narrow re-entrants in steep rocky stretches, at times, it will be economical to provide a bridge even if there is no water flow. Detailed cost analysis of bridge vis-a-vis rock cutting or providing a high retaining wall shall be done to arrive at an appropriate solution.

1.9.5 *Zigs*

When the space available on the hill face is not adequate to connect the two obligatory points within the ruling gradients or when heavy rock cut or potential slide zones are to be avoided, zigs are provided. The zigs are however trouble prone spots. Their location has to be carefully sited at reconnaissance stage in fairly flat hill side. During execution, the work may be commenced on the upper arm which is required to be taken well into the hill side and often becomes box cut. The lower arm is either in cut or cut-and-fill or on embankment. Extensive protective works like breast walls, catch water drains, lined box drains on upper arm, breast/retaining walls on lower arm and culverts with lined chutes between the two arms are required.

A typical sketch of zig is shown in **Fig. 1.7**.

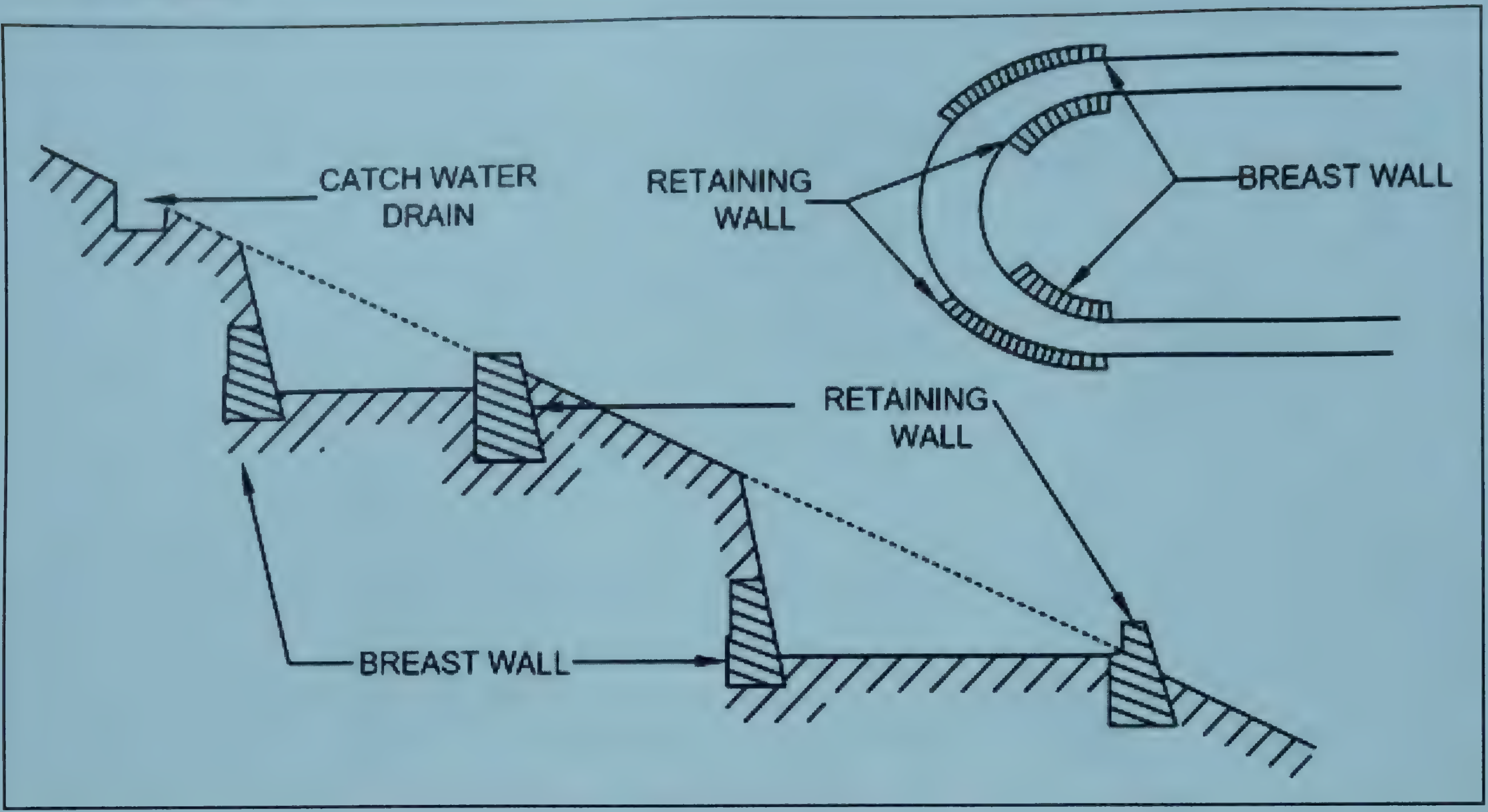

CATCH WATER DRAIN
RETAINING WALL
BREAST WALL
RETAINING WALL
BREAST WALL

Fig. 1.7 Typical Zig

1.9.6 *Sight Distance*

On sharp curves on spurs, visibility is restricted due to steep hill slopes. For safety of driving, bench cutting shall be provided on the hill side on the inner edge of the curve to improve visibility as shown in **Fig. 1.8**. These are also known as vision berms.

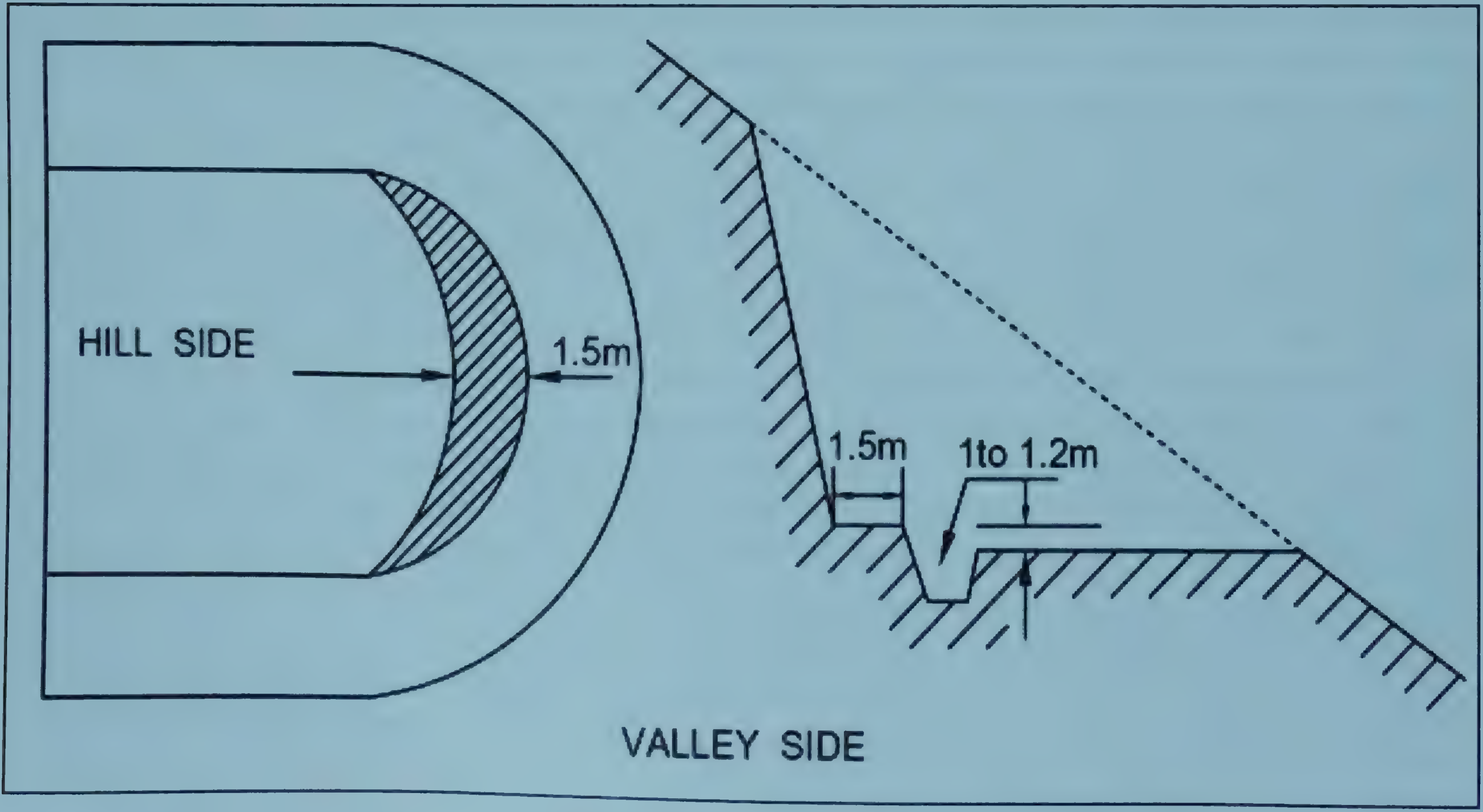

HILL SIDE
1.5m
1.5m
1to 1.2m
VALLEY SIDE

Fig. 1.8 Vision Berm

1.9.7 *Roadside Arboriculture*

Most of the hill roads (except those in snow clad areas) pass through forests or through fertile areas. As such, roadside arboriculture does not present any major problem. However, selection of right type of sapling, right season for plantation and proper upkeep for first one or two years must be attended to properly. Help of the local forest authorities may be sought for this purpose, wherever this is to be done. There should be provision for roadside arboriculture in the estimate.

1.10 Ecological/ Eco-Sensitive Zone/ Wildlife related issues

1.10.1 *Ecological and Environmental Aspects including Slope Protection Measures of formation of Road in Mountainous/ Hilly Areas*

The formation of road in a hill area, which is normally forest area, causes disturbance of environment due to jungle clearance, tree-cutting, movement of earth, altering slope stability/ slope cutting of hill face, rock blasting etc. and affecting flora and fauna. As such, every caution has to be taken in planning road cutting in hills so that least disturbance to environment is caused during construction as well as to arrest the chances of future disturbance of environment due to failure of slopes. Details on Ecology and Environment are given in **Chapter-13**. Special attention shall be given to the slope stability measures like gabions/wired masonry crates/breast walls/retaining walls/Geo-synthetics/metal fabrics duly anchored with steel nails/ reinforced soil structures/ rock fall protection measures or any other appropriate sound technology etc., with appropriate drainage arrangements of back fill, having structurally designed through sound engineering practices/means, so that the slope on cut earth/ mountain on hill sides as well as on filled up earth on valley side and the overlaid vegetation cover on both sides of the road is protected from erosion & sliding and debris is also protected from mingling with the streams. No slope on cutting as well as filling on hill/ mountainous roads shall be left un-protected. Each slope portion of the cutting and filling of the hill/mountainous road from tip/crown at top to co/ put at bottom of cutting/feeling shall be protected and made stable by providing/constructing slope stability structures in accordance with stability consideration as detailed in **Chapters 3 & 4**. Appropriate estimation of muck generation and its disposal at designated locations shall be made. The muck shall be disposed off at designated locations and retained by providing retaining engineering structures with appropriate drainage arrangements of back fill so that ingressed water may not carry soil fines along with it and all retained material is prevented from mixing with the streams. The muck disposal sites shall be covered by growing local variety of vegetation over it before completing of the work.

1.10.2 *Wildlife crossing-over Structures on Roads*

Roads and traffic exert a variety of direct, indirect and mostly detrimental effects on wildlife. Roads may cause wildlife mortality, inhibit wildlife movements and result in loss of habitat or habitat quality. Road development projects must consider the habitats and wildlife species present in project areas if they are to properly address and conserve biodiversity values. The wildlife crossing points on the road shall be identified. The road width in such pocket shall be increased and the slope protection works in such pockets shall be constructed in a way, so that crossing over by wild life is easier, so that their path/habitation remains undisturbed. Wildlife alert warning signages with flashing lights should be provided. Wildlife passage structure –Underpass (like elephant underpass) or overpass shall be constructed along with fencing to prevent animal crossing.

2. DRAINAGE AND CROSS-DRAINAGE

2.1 General

2.1.1 Topography of hill generates numerous water courses. This coupled with continuous gradient of roads in hills and high intensity of rainfall calls for effective drainage of roads. Uncontrolled flow of water is the primary cause of problems like soft surfaces, potholes, rutting, washed out shoulders, and even failure of complete sections of roadway structures. Prevention of such failures makes roads safer for motorists and pedestrians, reduces maintenance costs and adds immeasurably to the pleasure and satisfaction of the road users.

2.1.2 The cost of controlling water flow is a significant part of total highway construction cost. It is therefore important to plan and develop adequate facilities for drainage and erosion control.

2.1.3 A cardinal rule while planning drainage would be least interference with natural drainage. Ideally, this might be achieved by aligning all roads along ridges or drainage divides. For most roads, however, alignment is already determined by various other obligatory considerations. Minimum interference with natural drainage will mean stable earth face/surface with some kind of vegetative cover preventing erosion and allowing free drainage.

2.1.4 On hill roads, the moisture content in the sub-grade is liable to considerable seasonal variation on account of the following:

a) Water seepage through the adjacent hill face of the road.

b) Fluctuation in the water-table.

c) Percolation of water through the wearing surface.

d) Transfer of moisture/water vapour through different soil layers.

e) Snow fall and snow accumulation in the area.

2.1.5 Water flowing towards the road surface may be diverted and guided to follow a definite path and the flow on the valley side may be controlled so that stability is not affected. This will help in protecting the road bed and pavement. A network of drains helps in confining and controlling flow of water and thus check adverse effect on road structures. In hill roads, where the surface water and sub-surface water run rapidly towards subgrade, interceptor drains may be provided to trap the flowing water and prevent it from reaching the road side. In the lower slope i.e., near the pavement, the inflow of water in side drains will be local only. This can be intercepted by catch pits which will collect the flow from side drain, reduce velocity and divert the flow to cross drain/culvert for disposal.

2.1.6 When viewed in totality against the backdrop of the hills, the road acts as an interceptor and its longitudinal cut on hill slope obstructs the natural drainage and the road ledge therefore acts as a collection area of all water from hill side. As such, adequate drains in the form of catch water drains collecting flow from hill side to bring it to side drain leading to cross drains and further discharging into natural drainage channels through valley side drain/chutes (if erosion is likely to be on valley side), are essential for stability of road.

2.2 Hydrological Study of Rainfall and Snowfall

2.2.1 Precipitation on hill roads may be in two forms:

a) Liquid precipitation: i.e., Rainfall

b) Frozen precipitation: This consists of: I) Snow (II) Hail (III) Sleet (IV) Freezing

2.2.2 Runoff is that portion of precipitation which does not get evaporated. Runoff may be classified as:

a) Surface runoff

b) Interflow or subsurface runoff

c) Ground water flow or base flow

(i) Measurement of Rainfall

The amount of precipitation is expressed as the depth in centimeter which falls on a level surface and is measured by rain gauge which may be automatic or non-automatic type.

(ii) Runoff

The runoff of catchment area in any specified period is the total quantity of water draining into a stream or into a reservoir in that period. The principal factors affecting the flow from catchment area are:

a) Precipitation characteristics

b) Shape and size of the catchment

c) Topography

d) Geological characteristics

e) Meteorological characteristics

f) Character of the catchment surface

g) Storage characteristics

(iii) Computation of Runoff

The runoff can be computed either by empirical or rational formulae.

(A) Empirical formulae for peak runoff from catchment

Although records of rainfall exist to some extent, actual records of floods are seldom available sufficiently to enable the engineer to accurately infer the worst flood condition, for which provision has to be made in designing structures. Therefore, the help of theoretical computation has to be taken. Some of the most popular empirical formulae are:

a) Dicken's formula: $Q = CM^{3/4}$

where Q is the peak runoff in cum/sec and M is the catchment area in square km, C is a constant depending upon the rainfall.

b) Ryve's formula: (For Tamil Nadu Hills)

$Q = CM^{2/3}$

- These empirical formulae involve only one factor, viz., the area of the catchment. Many other factors that affect the runoff shall be considered while selecting an appropriate value of co-efficient. This is an extreme simplification of the problem and cannot be expected to yield accurate results.
- In recent years hydrological studies have been made and theories set forth which comprehend the effect of the characteristics of the catchment on the run-off. Attempts have also been made to establish relationships between rainfall and run-off under various circumstances. These formulae are not, however, strictly applicable to hill areas (especially in the North and North East) and as such, appropriate evaluations by collection of data from ground in each case may have to be resorted to.

(B) Rational Formula (Velocity Area Method)

The hydraulic characteristics of the stream that influence the maximum discharge are:

a) Velocity of flow

b) Slope of the stream

c) Cross-sectional area of the stream

d) Shape and roughness of the stream

In case of streams with rigid boundaries, the shape and size of cross-section is significantly same during a flood as well as after its subsidence. But when a stream is flowing in alluvium, the bed gets eroded during a flood and it gradually silts up again after the flood subsides.

(iv) Determination of Velocity

The velocity of a stream can be determined by:

a) Actual observation during a high flood

b) Use of empirical formulae

In making velocity observations the selected reach should be straight, uniform and reasonably long. The following methods are usually used:

a) Measurement of velocity by float

b) Measurement of velocity by pressure Instruments

c) Measurement of velocity by current meter

d) Empirical Formulae commonly used

I) **Manning's Formula:**

$$V = \frac{1}{N}(R)^{2/3}(S)^{1/2}$$

Where,

V = Mean velocity of flow in m/sec

R = Hydraulic mean depth = A/P

A = Cross sectional area in square metre

P = Wetted perimeter in metre

S = Bed slope

N = Coefficient of Rugosity

For measurement of the discharge, the cross-sectional area is generally divided into small vertical strips as shown in **Fig. 2.1**.

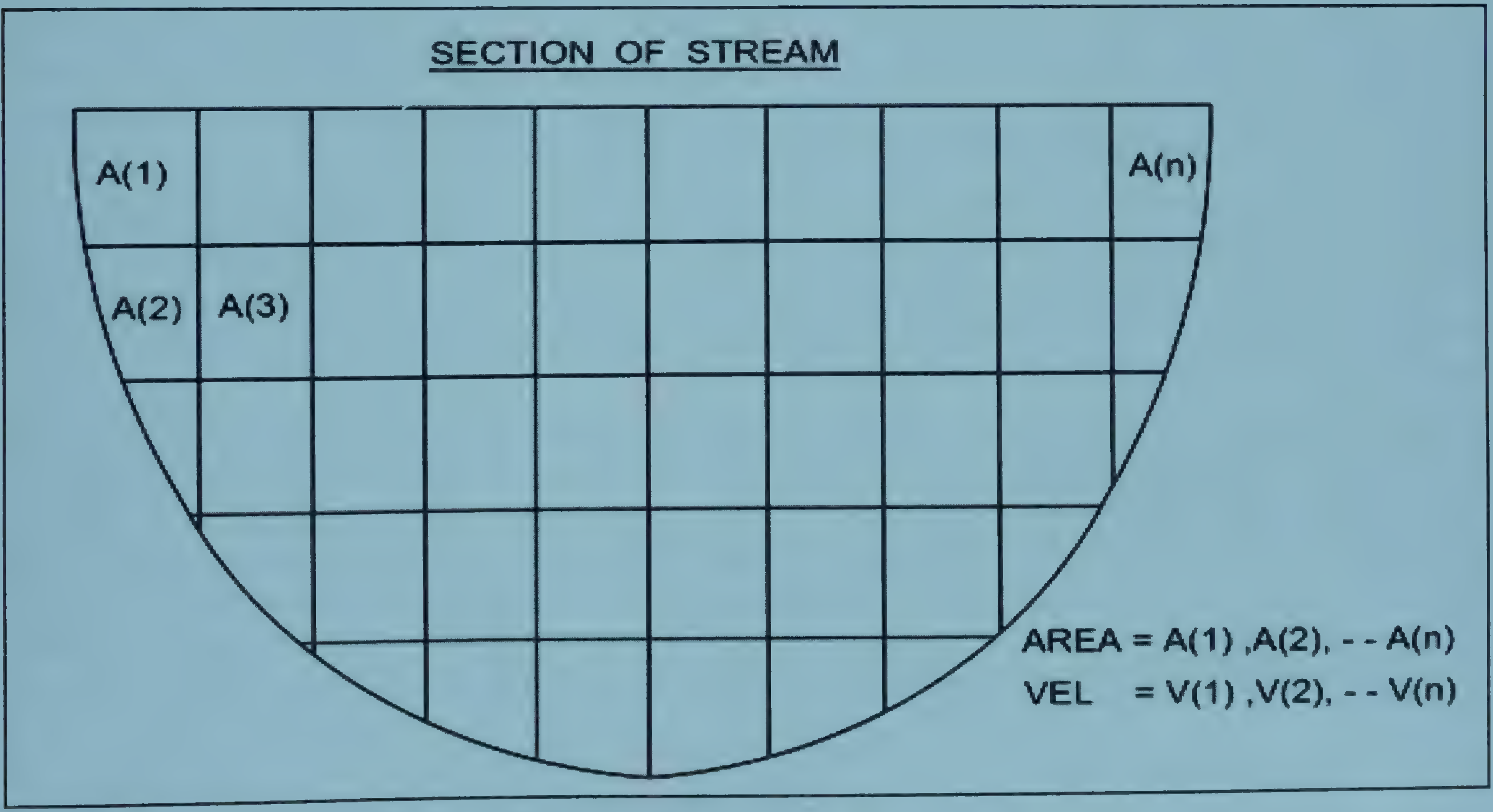


Fig. 2.1 Discharge by Area - Velocity Method

The width of the strip is so chosen that each strip be taken as a rectangle. The velocity of each compartment can be calculated with fair accuracy with any of the methods described earlier. The product of area of strip and mean velocity of the strip gives the discharge of the strip. The discharge of the channel can be obtained by summing up the discharge of all Individual strips.

If A (1), A (2) --- A (n) etc. are the area of the strips and V (1) V (2) --- V (n), are the corresponding mean velocities then the channel discharge is given by:

$$\text{Discharge } Q = A(1) \times V(1) + A(2) \times V(2) + \text{---} A(n) \times V(n)$$

$$= \sum (A \times V)$$

The normal practice is to compute the slope from the bed level at two cross-sections over a long distance. Since it is difficult to take any particular level in a cross-section at the bed level, it is recommended that the slope of the stream be calculated from one section at low water level each at upstream and downstream of the proposed site and same be treated as the correct slope.

The use of empirical formulae shall be as far as possible avoided. They are primitive and are safe only in the hands of an expert. The rational formulae explained above are the most commonly used in the determination of discharge.

2.3 Snow in High Altitude

2.3.1 Most high-altitude regions are subject to heavy snowfall during winter. The average snowfall varies from sector to sector depending upon various factors. In certain sectors, the annual snowfall is less than 1.5 mtrs, whereas there are sectors having moderate snow fall varying between 1.5 to 4 mtrs and heavy snowfall areas with average snowfall exceeding 4 mtrs. In sectors having snowfall not exceeding 4 mtrs the intensity and frequency of snowfall is considered not very high. The roads in such sectors are kept open to traffic during winter by resorting to snow clearance operation. In other sectors, the intensity as well as frequency of snowfall are so high that it is neither economical nor feasible to keep the road open to traffic mechanically or manually during winter (which are confined to some high passes only) and is cleared in spring by launching a major snow clearance operation.

2.3.2 At the end of winter, when there is steep rise in temperature, snow starts melting from top as well as from the bottom of frozen layers. As the coefficient of thermal conductivity of snow is high, the melting is always associated with enormous and instantaneous release of water. The water thus released, normally collects and flows on the road pavement in the absence of any outlet due to snow accumulation or ice formation.

2.3.3 Runoff from snow varies with its physical characteristics. The physical characteristics vary with the region depending upon meteorological conditions. Snow is classified as crystalline, granular, powdery pallet snow or mixtures. For runoff purposes, it will be appropriate to classify snow as dry, damp and wet according to moisture content/density. Snow density varies from 0.40 - 0.45 (fresh snow) to 0.7- 0.8 (wet snow). The snow with low density is termed as dry whereas snow having moderate and high density are termed as damp and wet snow respectively. **Chapter-6 on "Snow Clearance and Avalanche Treatment"** gives details of snowfall, its effects etc.

2.4 Roadside Drains

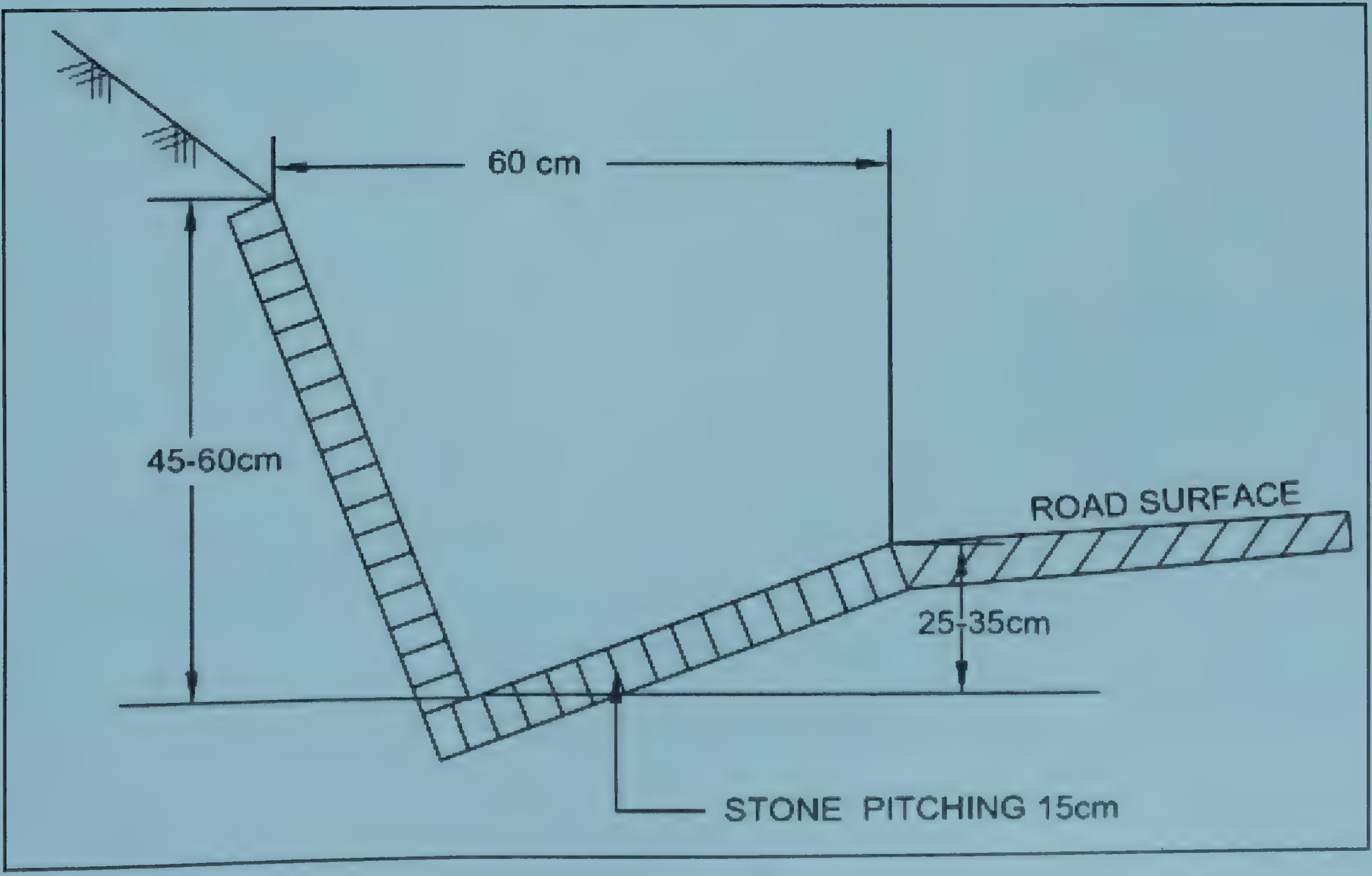
2.4.1 Inadequate cross drainage on a hill road causes softening of the subgrade and renders it too weak to take the load of the moving traffic. Roadside drains are therefore necessary on a hill road. They shall be taken below the subgrade of the road or in a kutcha road these shall be invariably taken about 300 mm below the road surface. Where cross fall and super elevation oppose each other in valley side curves, proper arrangement in the layout of drain shall be done.

2.4.2 Roadside drains should generally be of uniform section throughout its length irrespective of the location of road on the hill slope. Road on ridge alignment may not require the same section of drains due to lesser quantity of flow of water. For convenience of construction, it may be necessary to have uniform section of a drain but the frequency of culverts could be regulated by the catchment area that it has to cater for.

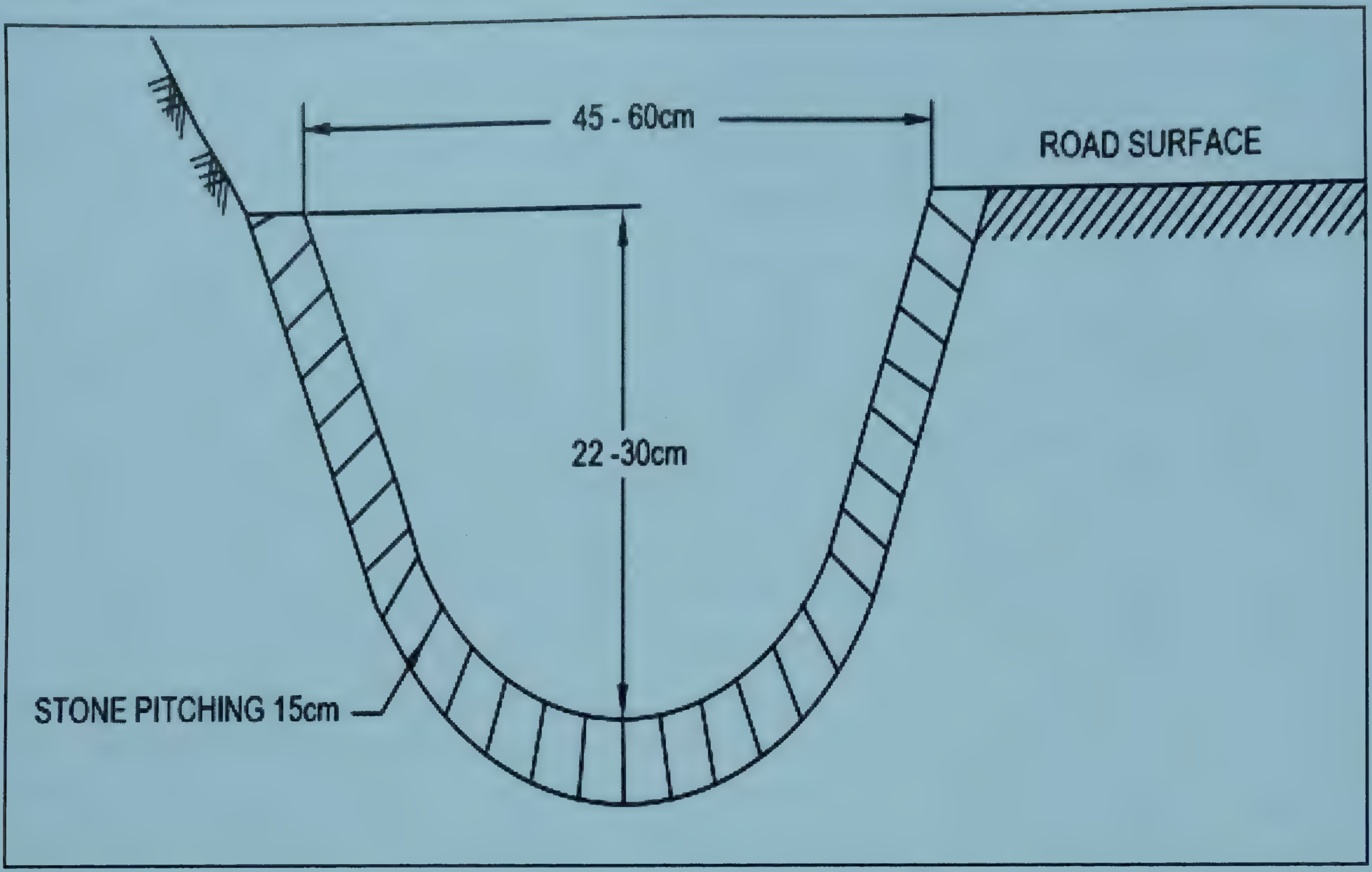
(a) Roadside drains are constructed to parabolic (Saucer shape), trapezoidal, triangular, V-Shape, kerb and channel or U-Shaped cross-sections. The parabolic section is hydraulically the best and most erosion resistant. The trapezoidal sections are easier to construct and are more generally used. Kerb and channel drain gives extra width in case of emergencies for vehicles to use. U-Shaped drains are generally deep drains and are provided where higher discharge is to be catered and adequate road width is available. Kerb & channel drains and V shaped drains are provided along raised pucca footpath in built up area.

(b) Generally drains are made of size 60 cm x 60 cm and should have a gradient of 1:20 to 1:25 to develop self-cleansing velocity to disperse floating debris conveniently. In continuous long stretches of road with steep grades, the roadside drains shall be stepped to break the velocity. As an integral part of side drain, a 0.6 m high toe wall along the hill side shall be provided to prevent erosion of hill-slope. In U-Shaped drain, roadside edge shall be provided with guide stones (duly whitewashed) to maintain distance of vehicles for safety. **Fig. 2.2** gives details of various types of side drains and their arrangements.

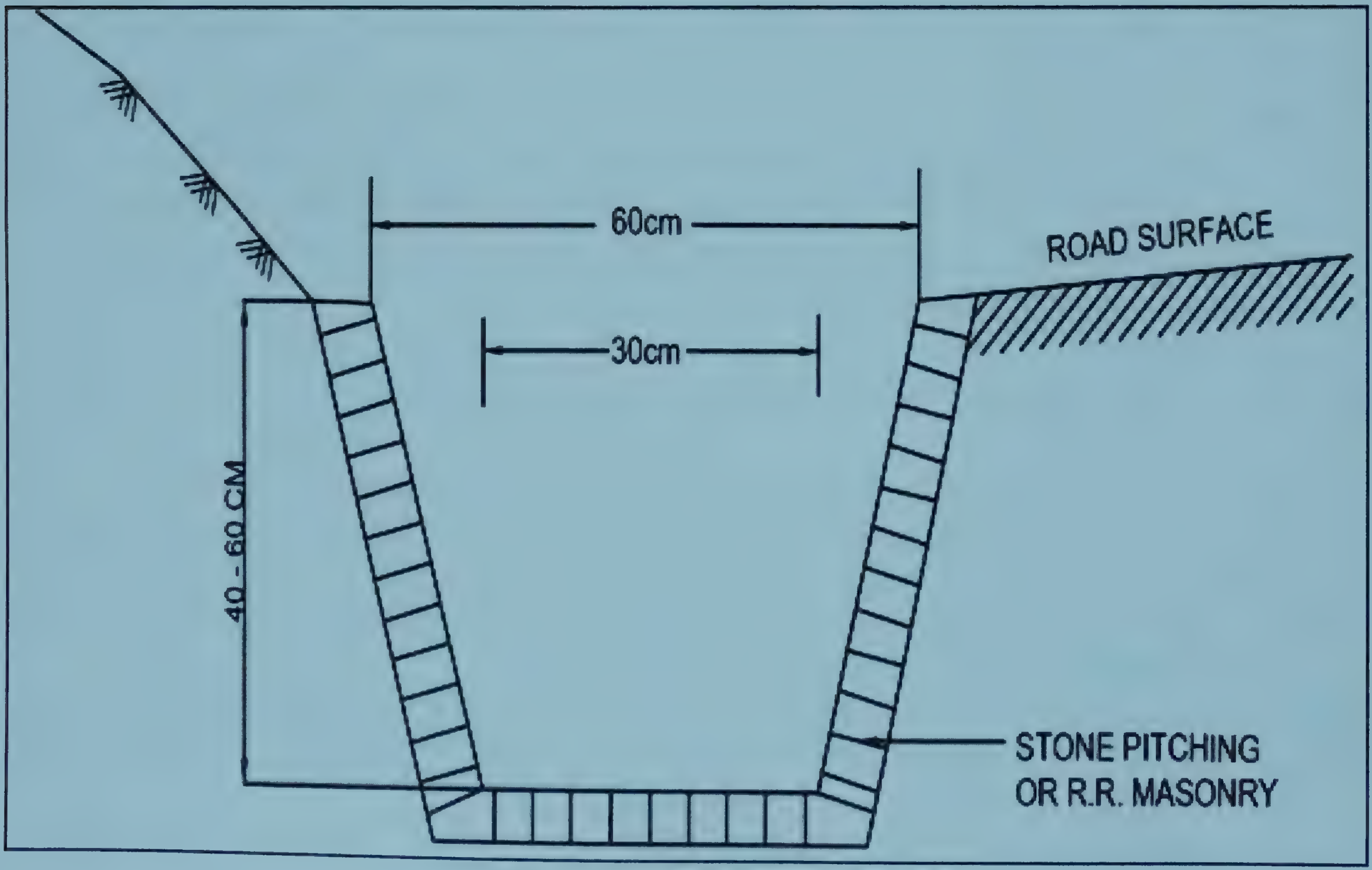
(c) To discharge runoff from hill side, to valley side generally 8 to 10 culverts/or as per site requirement shall be provided per km length of Hill Roads or the side drains may be connected to discharge into natural water course.



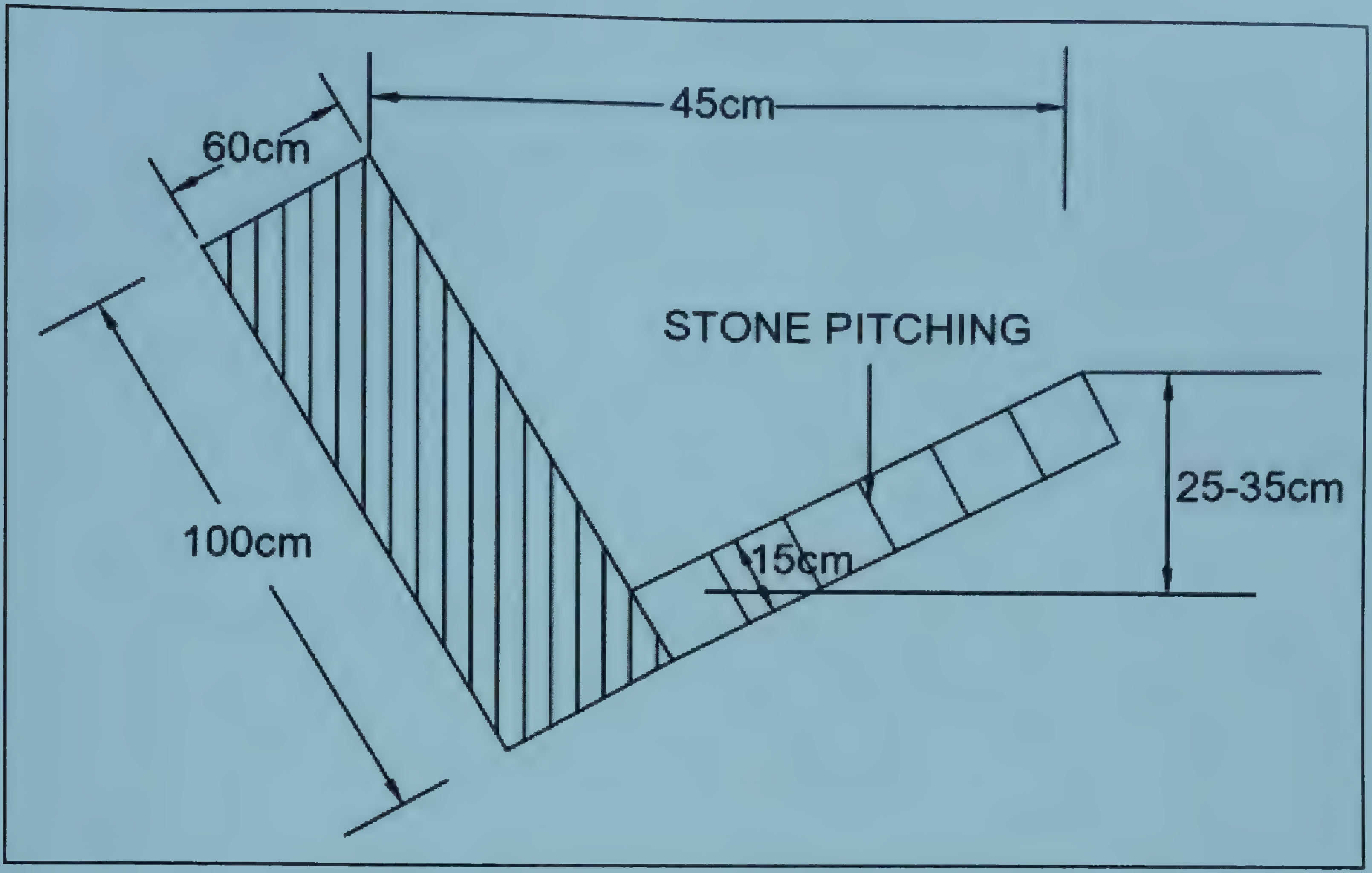
(a) V-Shaped Drain


45 - 60cm
ROAD SURFACE
22 -30cm
STONE PITCHING 15cm

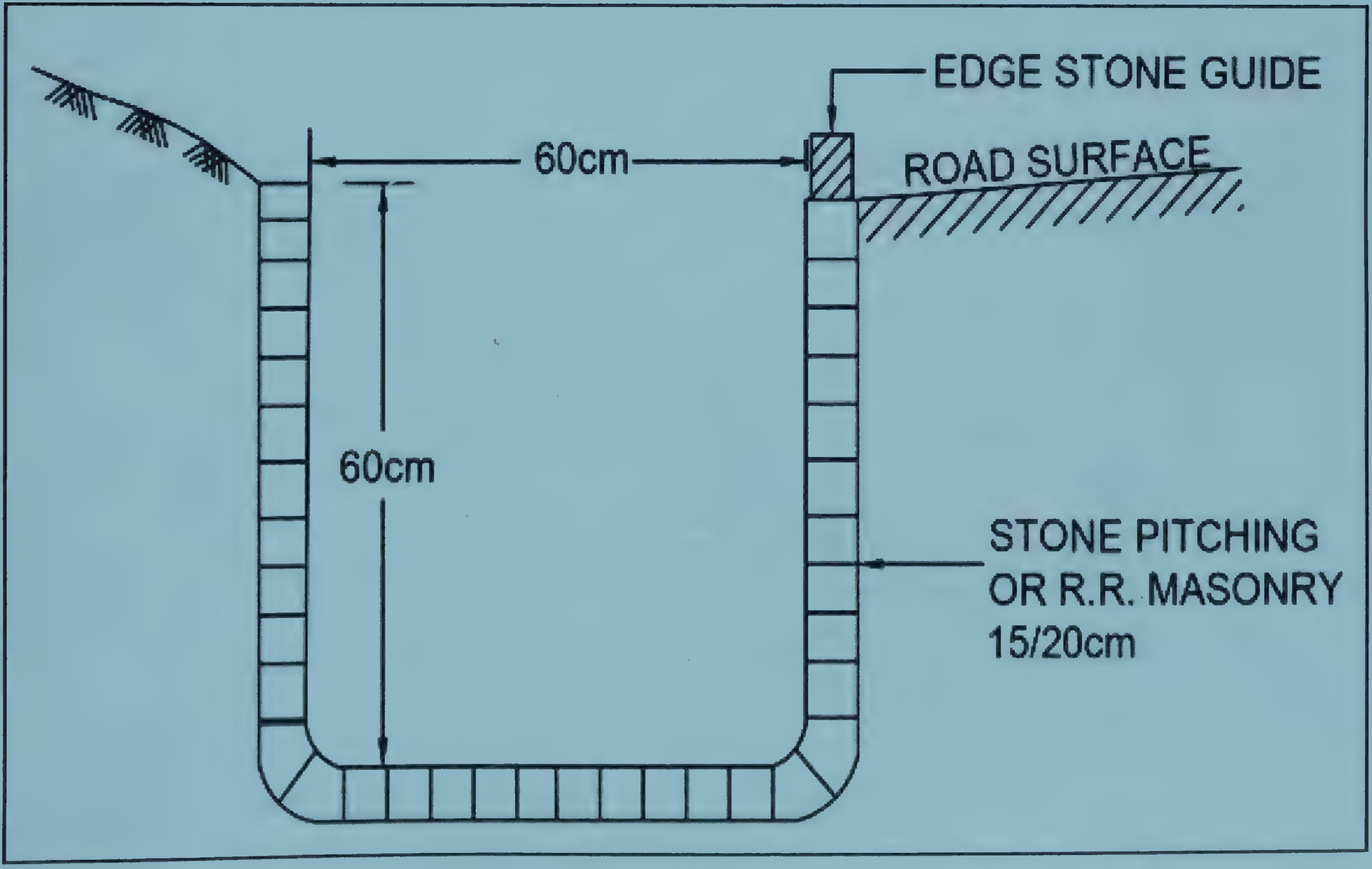
(b) Parabolic or Saucer Type Drain


60cm
ROAD SURFACE
30cm
40 - 60 CM
STONE PITCHING
OR R.R. MASONRY

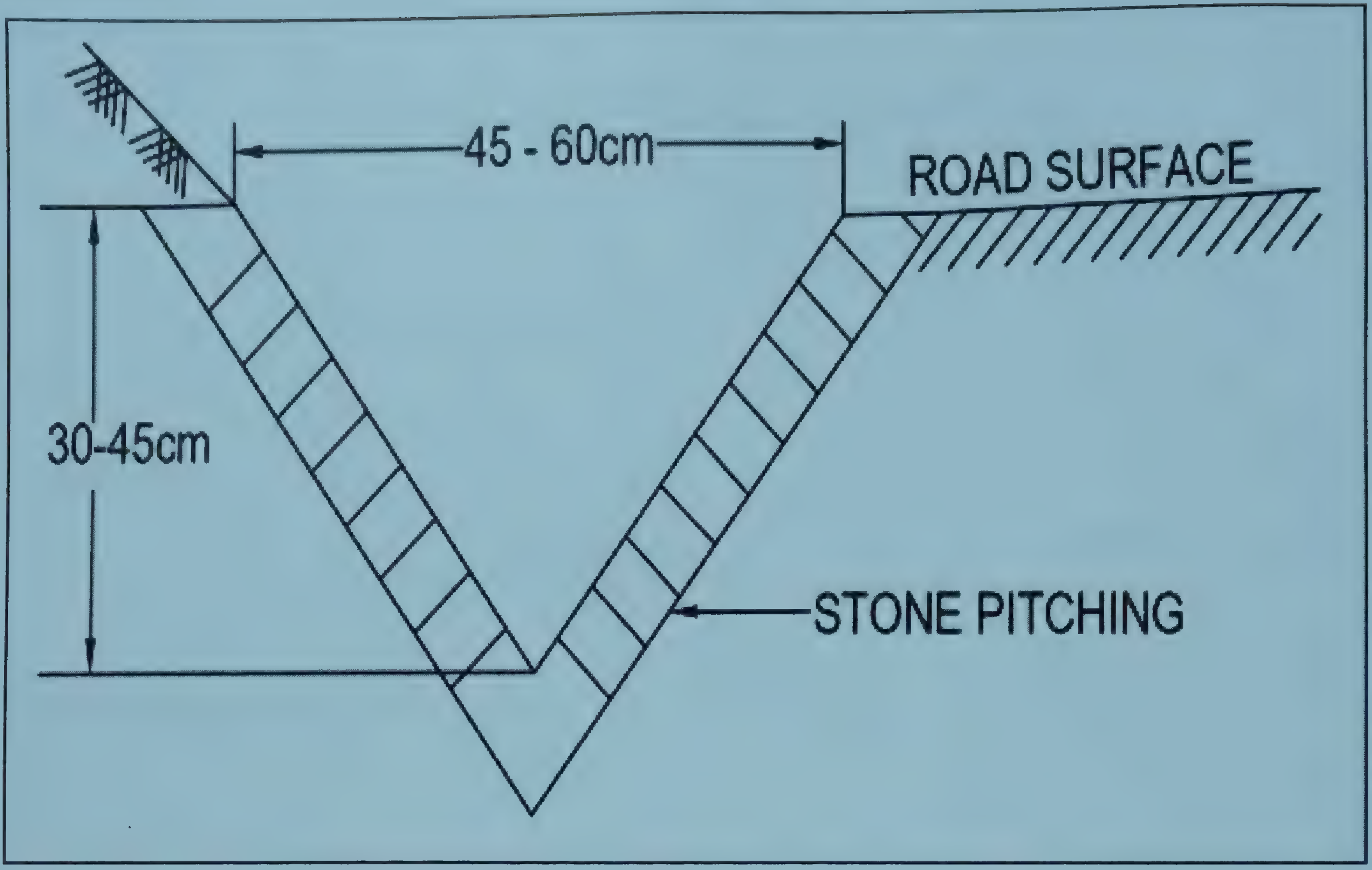
(c) Trapezoidal Drain


60cm
45cm
STONE PITCHING
100cm
25-35cm
15cm

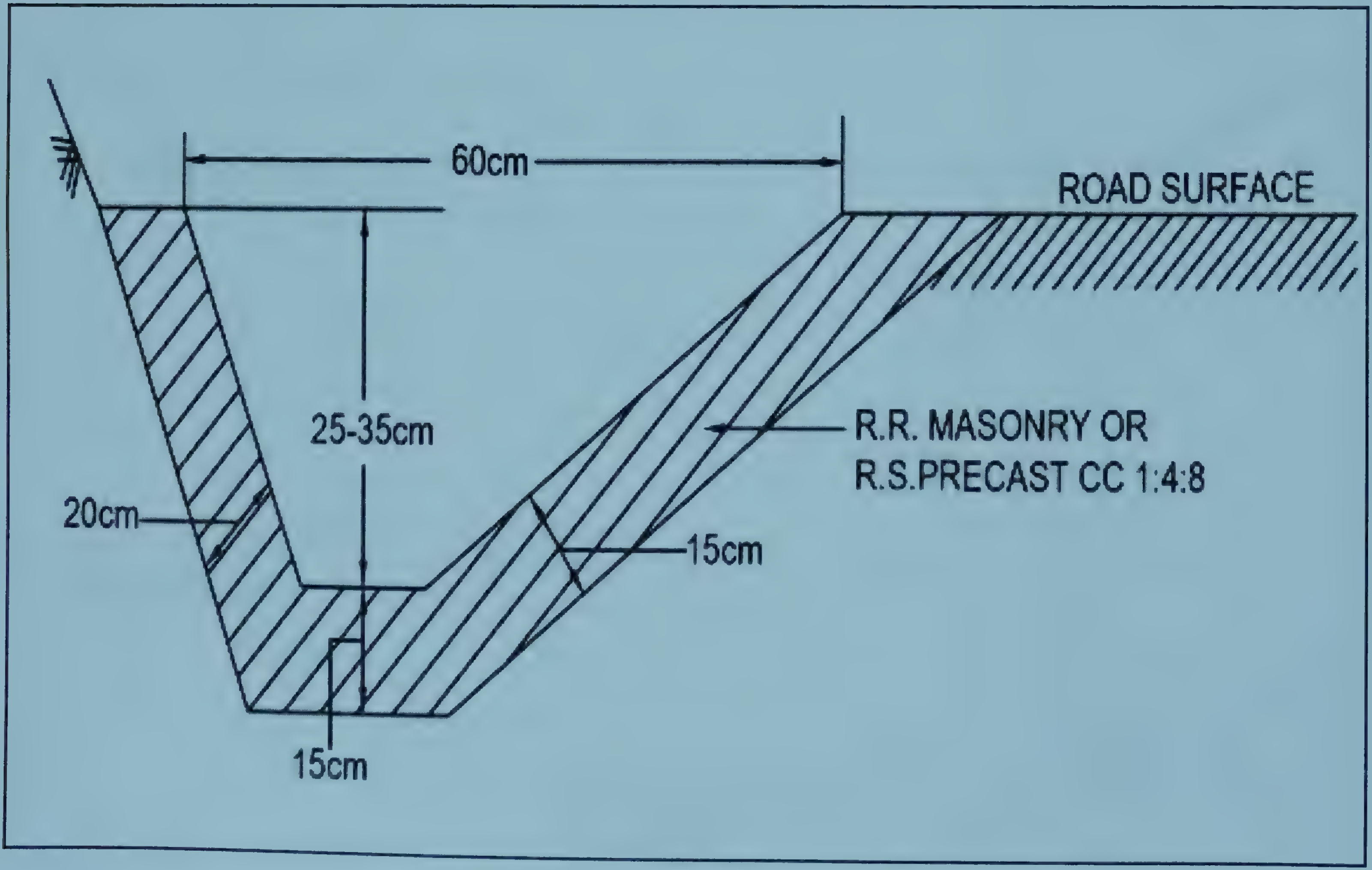
(d) Typical Section Toe Wall & Drain


EDGE STONE GUIDE
60cm
ROAD SURFACE
60cm
STONE PITCHING
OR R.R. MASONRY
15/20cm

(e) U-Shaped Drain


45 - 60cm
ROAD SURFACE
30-45cm
STONE PITCHING

(f) Triangular Drain


60cm
ROAD SURFACE
25-35cm
R.R. MASONRY OR
R.S.PRECAST CC 1:4:8
20cm
15cm
15cm

(g) Kerb and Channel Drain

Fig. 2.2 (a to g) Side Drains

2.5 Catch-Water Drains/Intercepting Drains

2.5.1 Such drains are provided on hill slopes to intercept water flowing from upper reaches and guide such flow into culverts. These drains should be of trapezoidal shape and should be at least stone lined and cement pointed. Catch water drains must carry the intercepted water to the nearest cross-drainage point and it should be well cleaned and repaired before the onset of every monsoon.

2.5.2 Such catch-water drains shall be provided in stable hill slopes outside the periphery of slide/unstable areas so that stability of hill is not further worsened. In such cases, additional intermediate drains may also have to be provided in some cases depending on ground conditions. **Figs. 2.3 & 2.4** depict catch-water drain arrangement on a stable hill slope and in a slide area.

2.6 Chutes

2.6.1 Surface runoff on a hill slope generally flows down in the form of natural gullies/chutes. The water entrapped in the catch water drains is also brought down either by connecting them with existing natural gullies or through specially provided chutes. The cumulative discharge with its increasing momentum causes immense erosion. Therefore, lined chutes shall be provided mandatorily to lead the discharge to the catch pit of culvert or to a natural drainage channel or to the catch pit of culvert and further from the outfall of the culvert upto a natural drainage channel, if it is away from the culvert outfall so as to dissipate the momentum/energy of falling water out of the culvert outfall (**Fig. 2.5**). Box type stepped chutes of stone masonry have been found more appropriate because of their stability and long life. A typical section is given in **Fig. 2.6**.

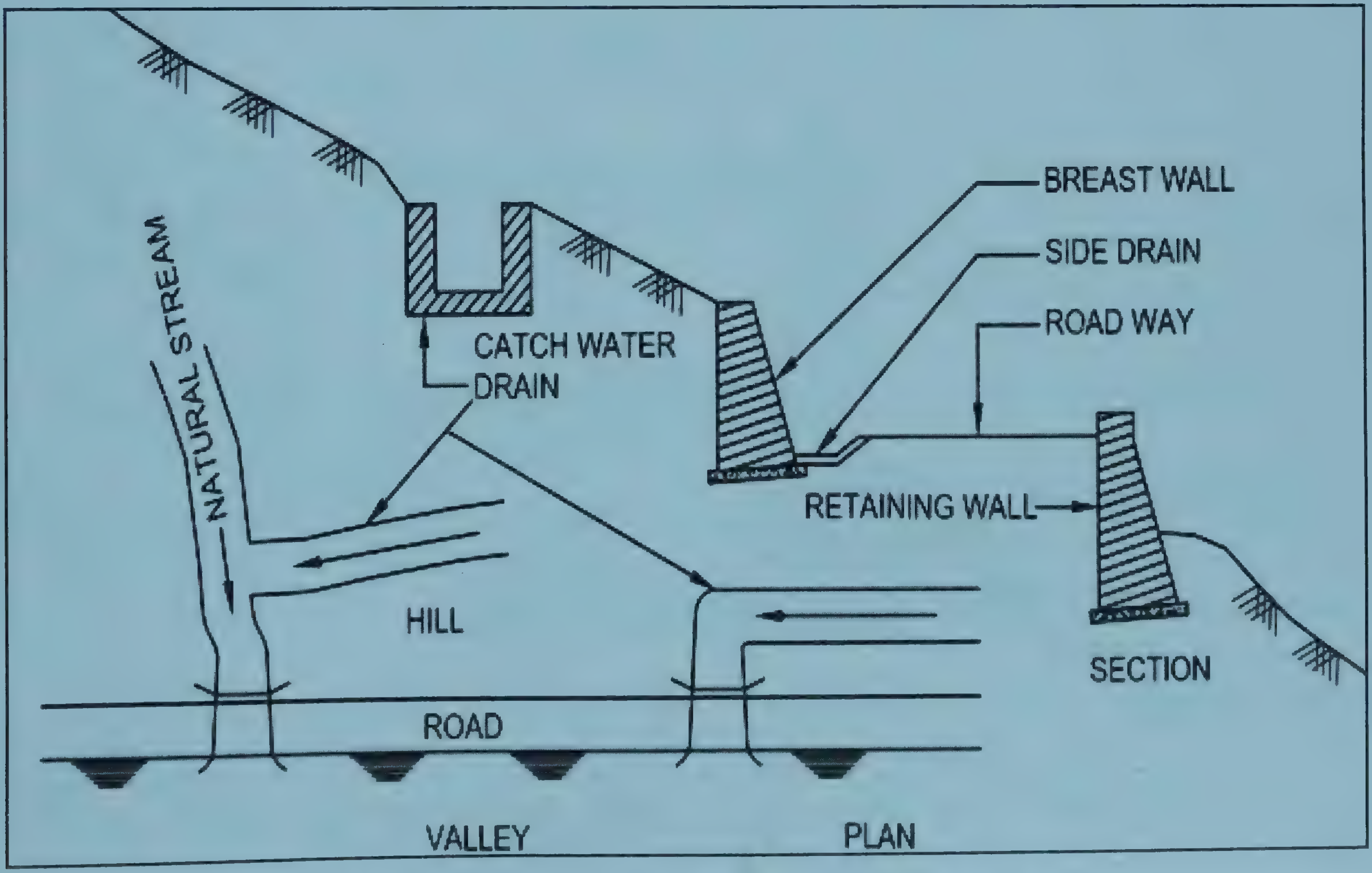


Fig. 2.3 Catch-Water Drain in Stable Area

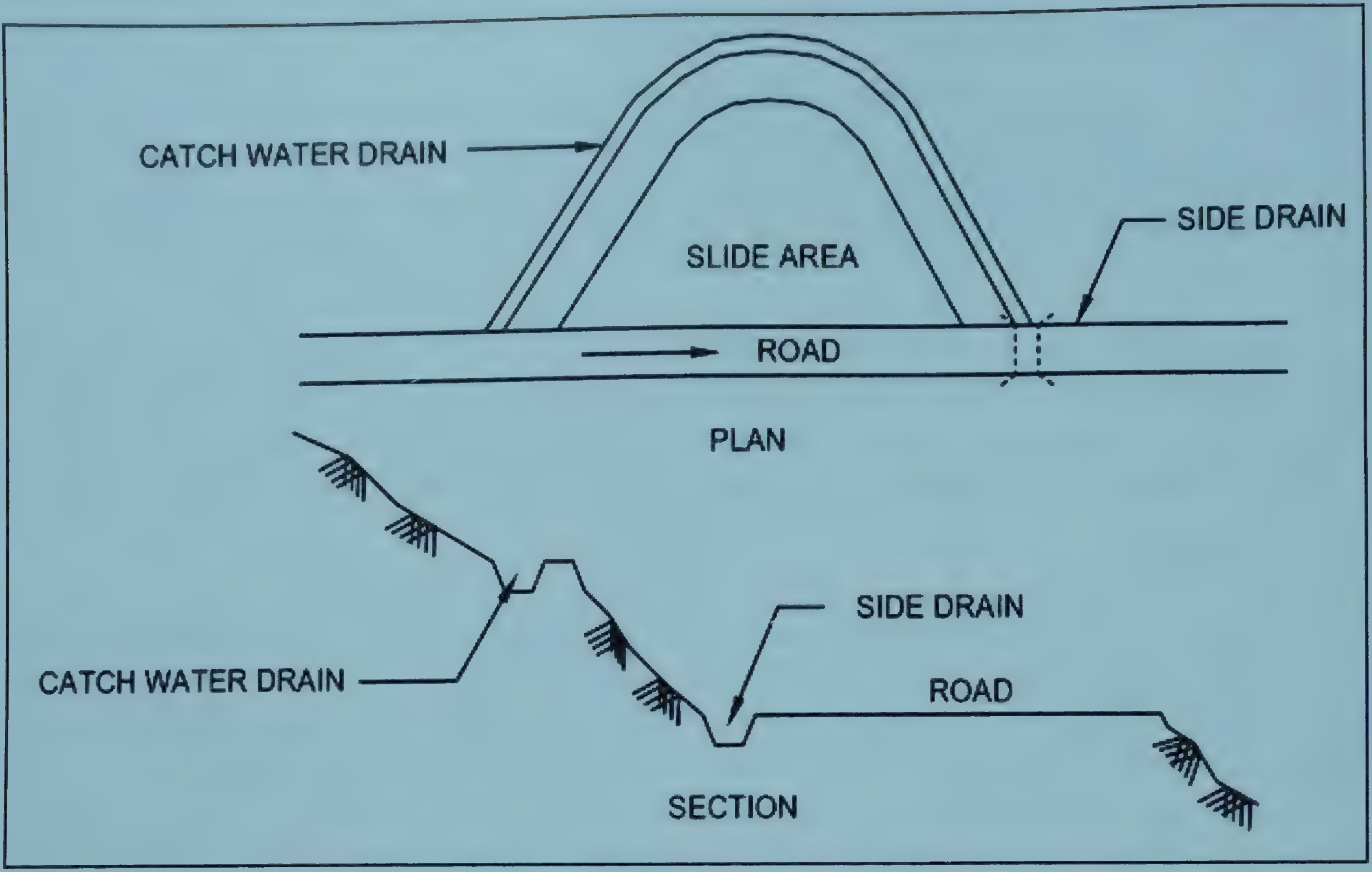

CATCH WATER DRAIN
SLIDE AREA
SIDE DRAIN
ROAD
PLAN
SIDE DRAIN
CATCH WATER DRAIN
ROAD
SECTION

Fig. 2.4 Catch-Water Drain in Slide Area

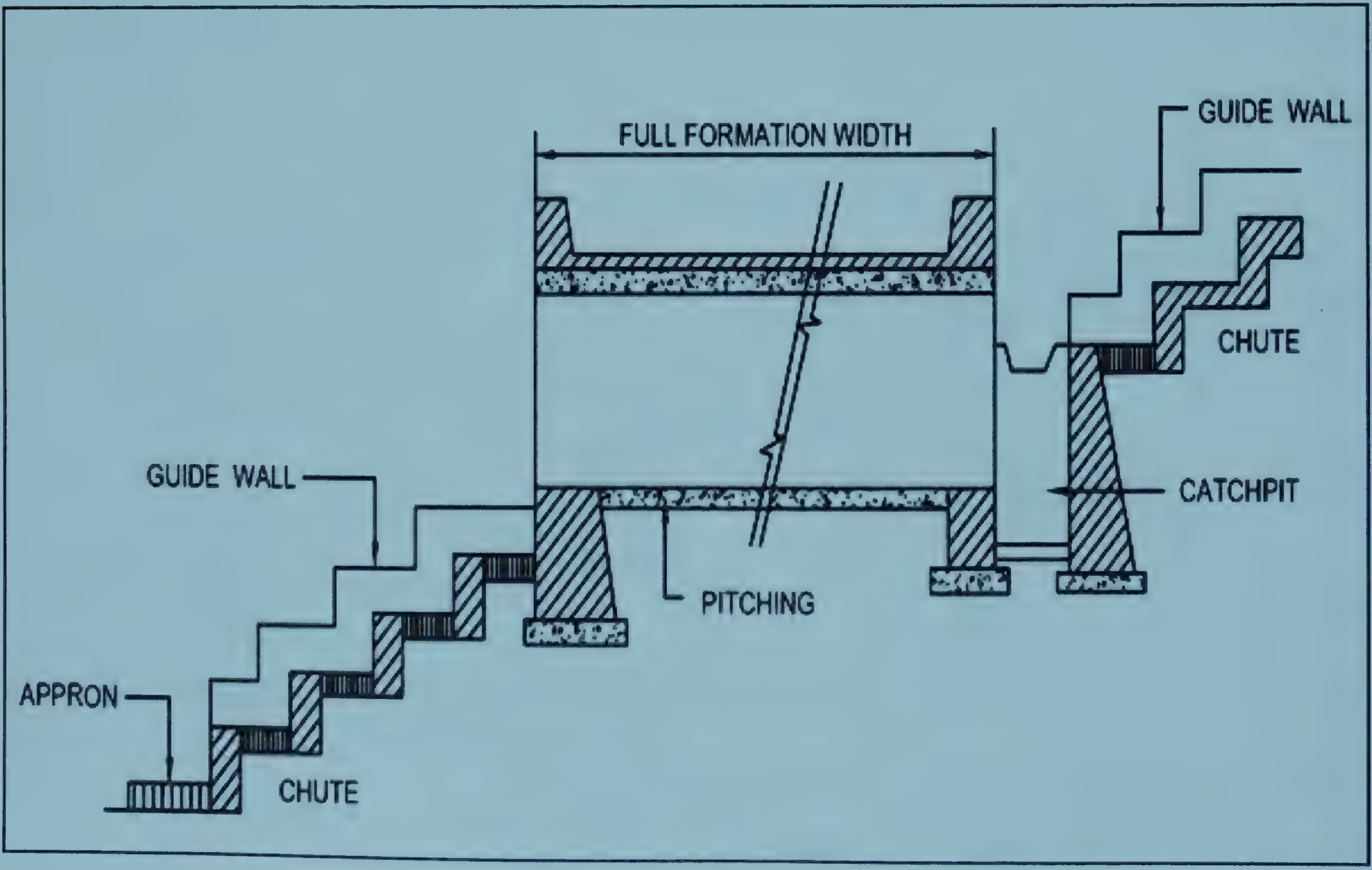
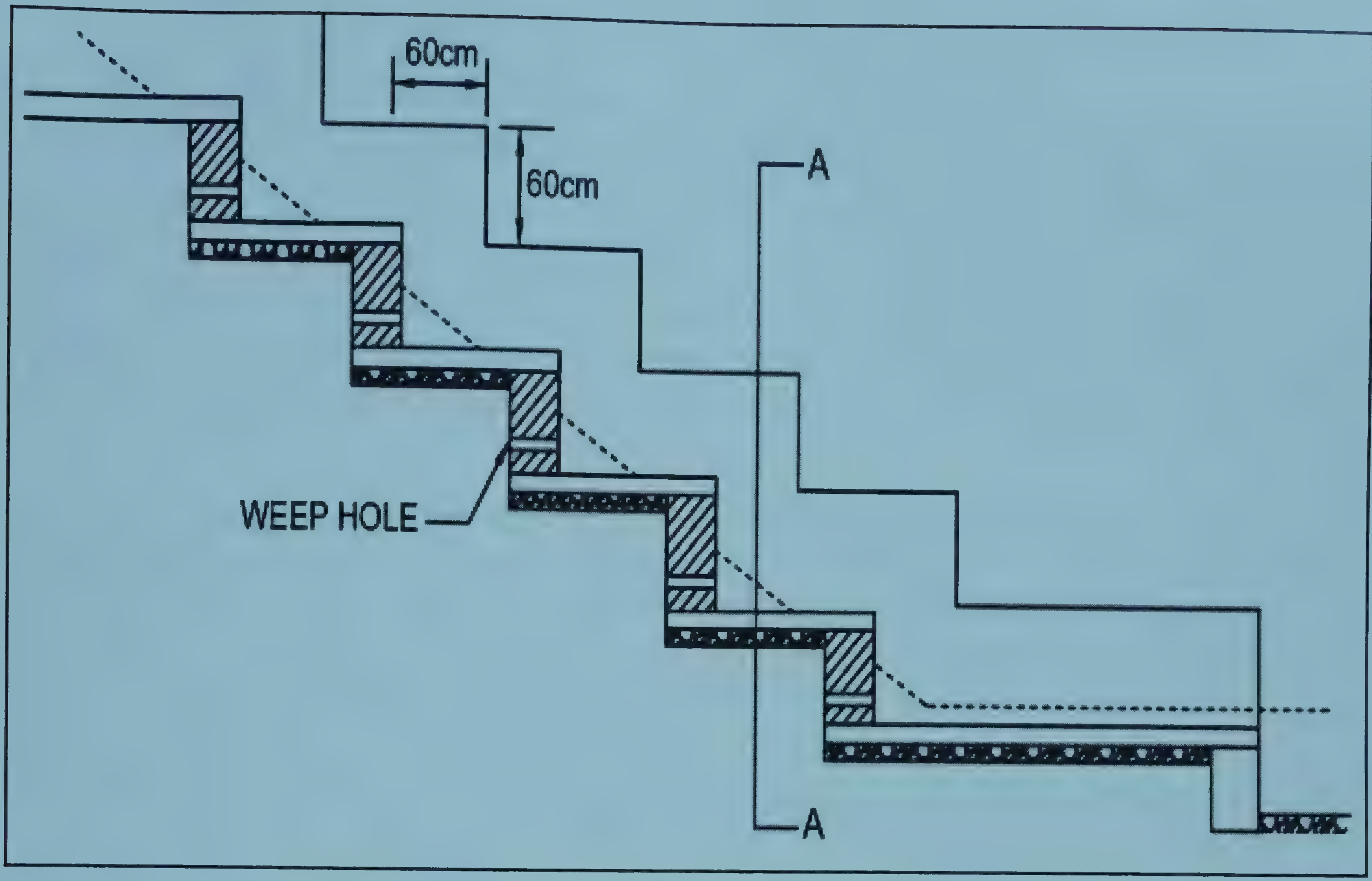
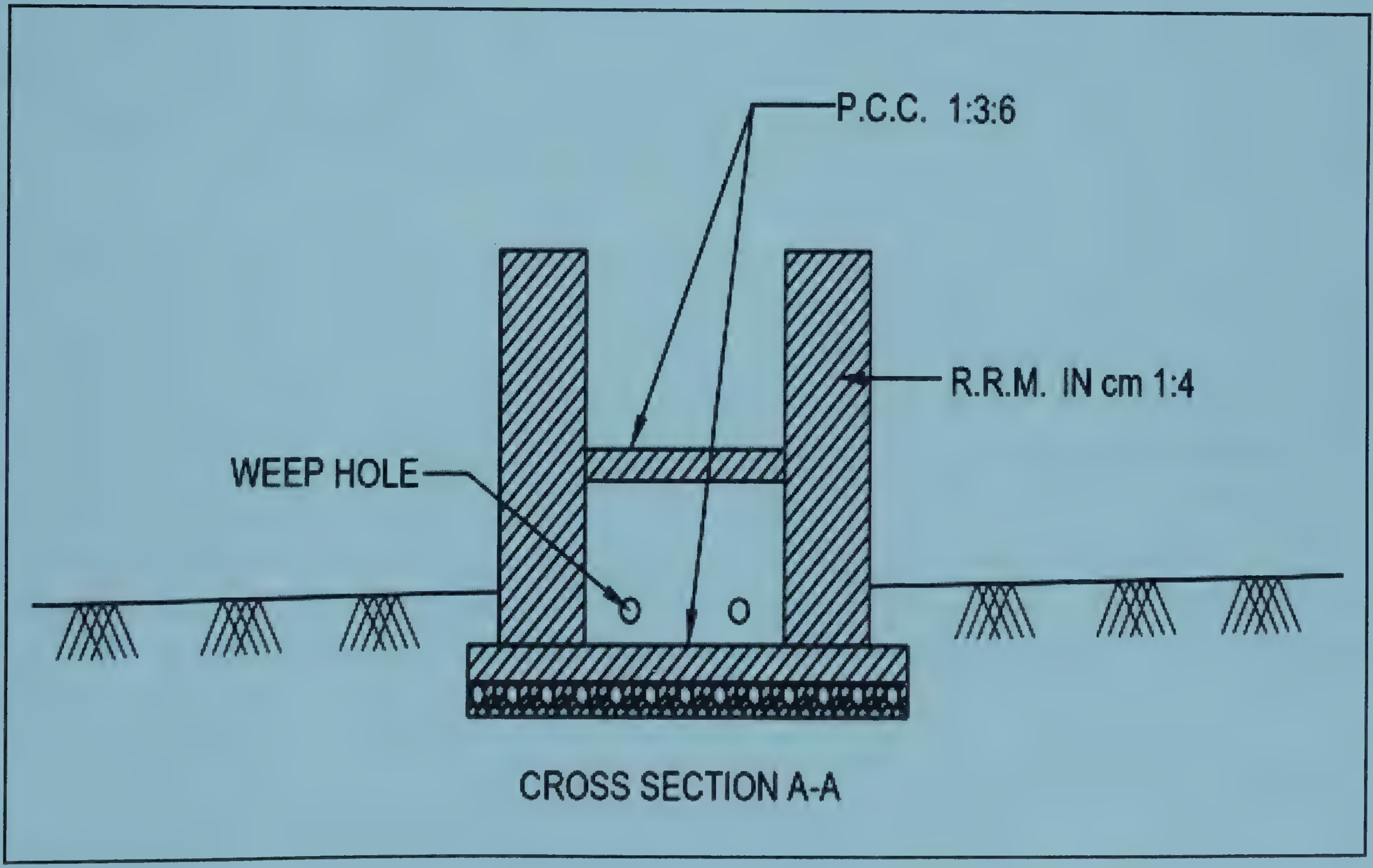

GUIDE WALL
FULL FORMATION WIDTH
CHUTE
CATCHPIT
GUIDE WALL
PITCHING
APPRON
CHUTE

Fig. 2.5 Culvert with Catchpit, Chute, Guide Wall and Apron


60cm
60cm
A
A
WEEP HOLE

Longitudinal Section of Chute


P.C.C. 1:3:6
R.R.M. IN cm 1:4
WEEP HOLE
CROSS SECTION A-A

Cross Section A-A

Fig. 2.6 Cross Sections of Chute

2.7 Pavement Drainage

2.7.1 Drainage problem may be considered in two-categories, surface and subsurface. Surface drainage or in other words, pavement drainage includes the disposal of all water present on the surface of the pavement and adjacent ground.

2.7.2 In the case of re-entrants, which necessarily have to be cross drainage points, cross fall is given towards the valley side. Surface drainage shall provide for the surface water runoff from the carriageway/shoulders. The surface runoff, which is mostly due to local rainfall on the road way is allowed to flow down quickly to the adjacent natural ground where appropriate cross fall is available.

2.7.3 The water collected on the surface of road and the adjacent ground is taken away by the side drains and disposed of into natural water courses nearby. As such, the berms/shoulders shall be well dressed and maintained to drain off the surface water either towards valley side or hill side. Roads in areas subject to heavy rainfall and snowfall are generally provided with hard or surfaced shoulders. It has been seen in actual practice that inadequate provision of proper cross fall/longitudinal gradient coupled with the temporary overflow of side drains, damages the shoulders considerably and the water finds easy access into the subgrade thereby causing damage to the pavement. Overflow along the road length damages the shoulders on the valley side.

2.7.4 Adequate care shall be taken in geometrics to ensure channelized drainage to avoid damage to road shoulders. On the valley side, protective parapets with intermittent gaps will help to drain off surplus water. In straight reaches, camber to the road surface shall be provided for disposal of surface water. Use of granular soil in slushy reaches has been found useful.

2.8 Subsurface Drainage

2.8.1 Increase in the moisture content of subgrade reduces its strength and bearing capacity and hence it should be ensured that the moisture content in the subgrade is kept as minimum as possible. Further, changes in the moisture content of clayey soil in the subgrade may lead to corresponding volume changes, i.e., swelling of the soil takes place with increase in moisture content. In order to correct these problems, it is necessary to install drains below ground level which will intercept and carry the groundwater to a stream or open drainage system.

2.8.2 The various causes due to which changes in soil moisture content occur below a pavement are indicated in **Fig. 2.7.** To counteract such possible changes, a subsoil drainage system should be provided on these sections of the road wherever necessary.

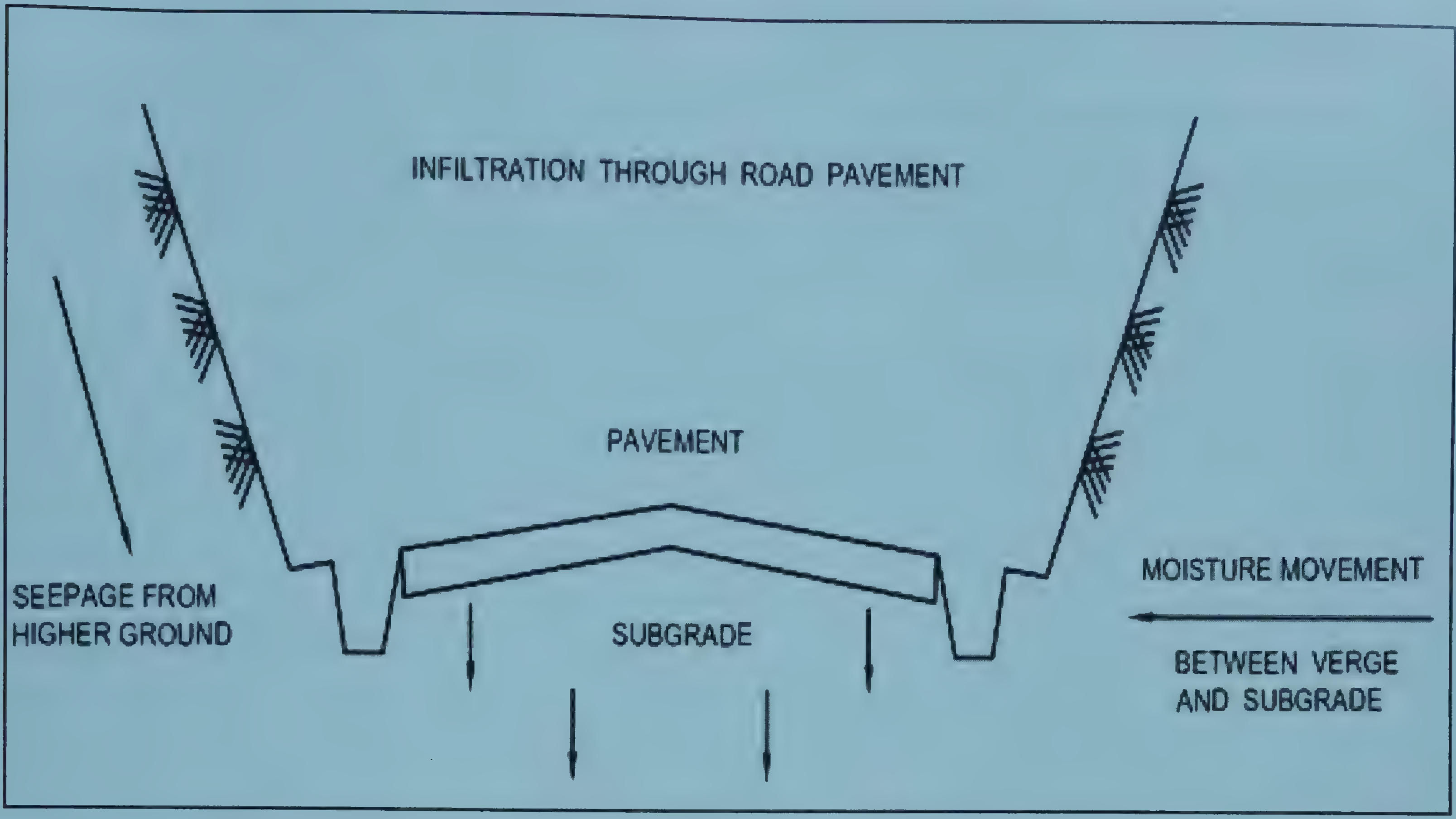

INFILTRATION THROUGH ROAD PAVEMENT
PAVEMENT
SEEPAGE FROM HIGHER GROUND
SUBGRADE
MOISTURE MOVEMENT
BETWEEN VERGE AND SUBGRADE

Fig. 2.7 Moisture Movement Resulting from Rise and Fall

2.8.2.1 *Transverse Trench Drains*

Transverse trench drains are generally made below the road pavement in a sinking area to facilitate the drainage of seepage water from the hill slopes without damaging the road structure. Sausage blocks of 1.2 m x 1.2 m in a trench of 1.8 m width are constructed on uphill and downhill site. In between these blocks, boulders are properly packed to take the load of road structure and traffic over the transverse trench. **Fig. 2.8** shows the cross section of Transverse Trench Drain.

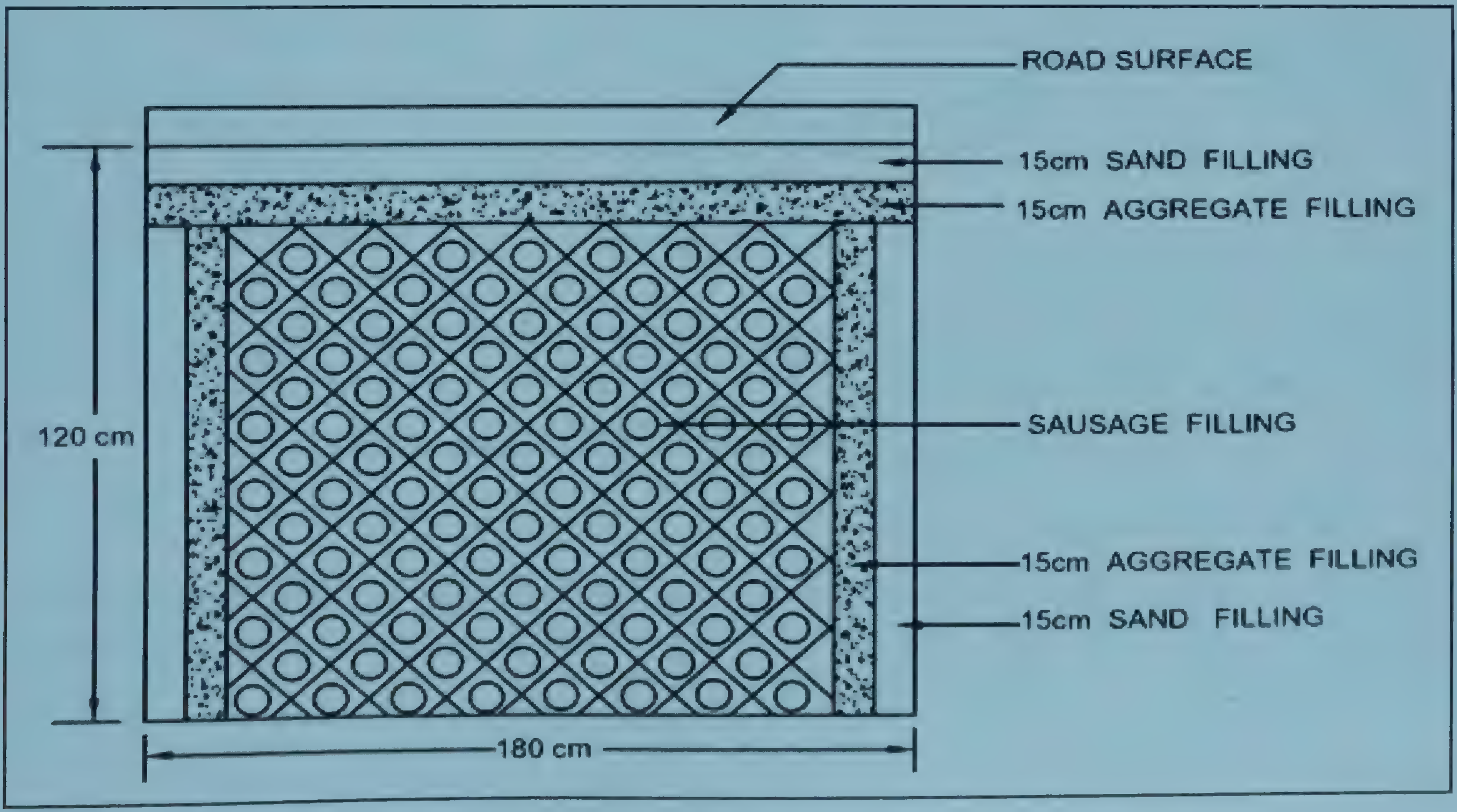

ROAD SURFACE
15cm SAND FILLING
15cm AGGREGATE FILLING
SAUSAGE FILLING
15cm AGGREGATE FILLING
15cm SAND FILLING
120 cm
180 cm

Fig. 2.8 Cross Section of Transverse Trench Drain

2.9 Application of Subsurface Drains

2.9.1 *Seepage from High Ground*

Seepage from high ground occurs when a layer of permeable soil overlies an impermeable layer. Cut slopes, which continually slough away at a point where free draining water reaches the face can be stabilized by installing subsoil drains at back of the cut face.

In such cases, a drain shall be constructed as a cut-off drain and installed to a depth slightly below the previous material and backfilled with clean sand. The drain shall be wrapped using a non-woven geotextile filter to prevent blockage. A pipe drain wrapped with non-woven geotextile filter is usually bedded on stone or lean concrete on impervious material to prevent water from collecting underneath the pipe and eventually causing deterioration of the subgrade. The underground water is carried away in the drain to an outlet or a stream, removing the cause of sloughing. When the impermeable stratum is at a lower level and the seepage zone is deep, it is generally not practicable to intercept all the seepage water and the intercepting subsurface drain is positioned so as to keep the seepage water at least one metre below formation level. **Fig. 2.9** shows a subsurface drain intercepting free water in a slope before it reaches the face where it would cause sloughing or sliding.

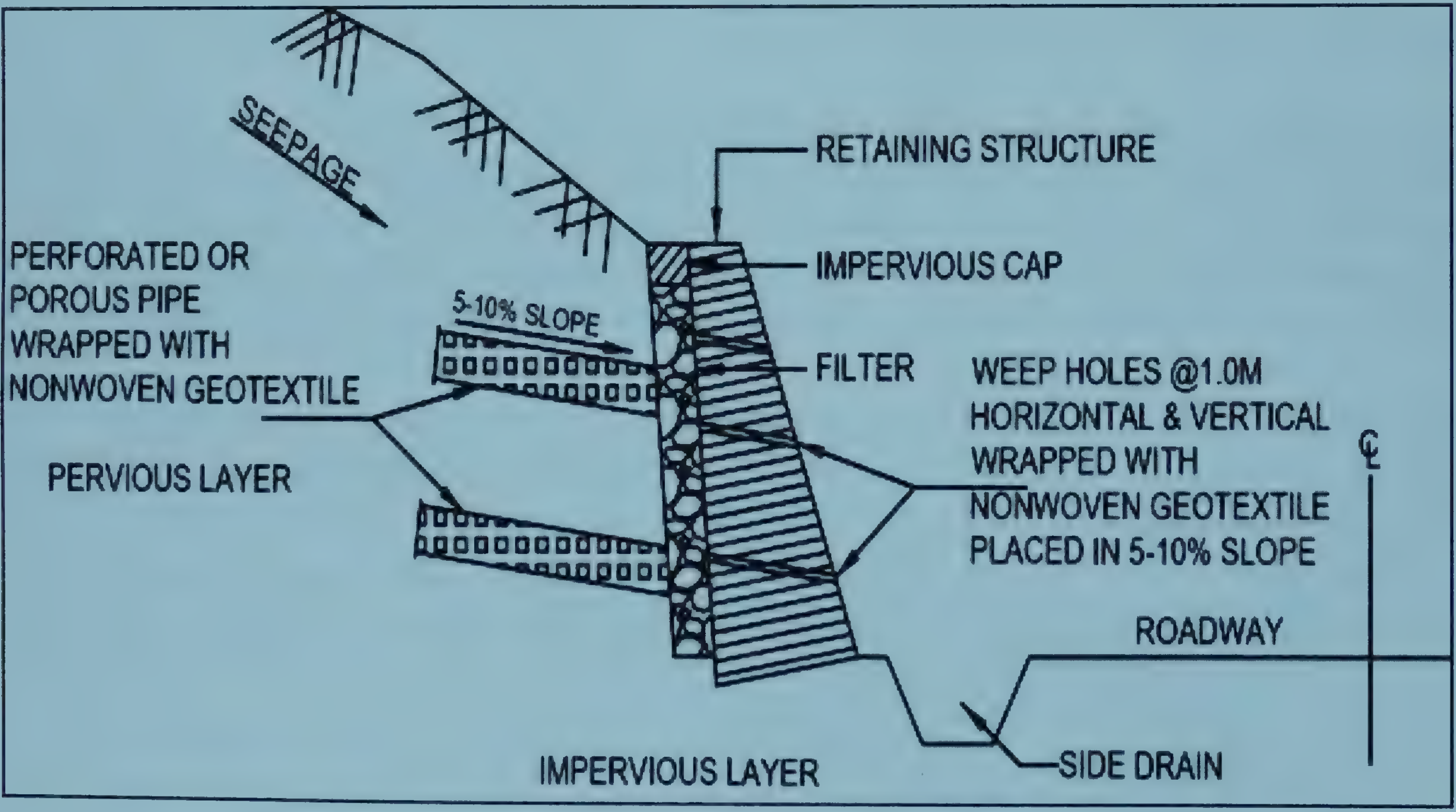

SEEPAGE
RETAINING STRUCTURE
PERFORATED OR POROUS PIPE WRAPPED WITH NONWOVEN GEOTEXTILE
IMPERVIOUS CAP
5-10% SLOPE
FILTER
WEEP HOLES @1.0M HORIZONTAL & VERTICAL WRAPPED WITH NONWOVEN GEOTEXTILE PLACED IN 5-10% SLOPE
PERVIOUS LAYER
℄
ROADWAY
IMPERVIOUS LAYER
SIDE DRAIN

Fig. 2.9 Seepage from High Ground Subsoil Drain

2.9.2 *Subgrade Drainage*

The underground water flows in a layer near the road surface. This water can weaken the road and create soft spots and rutting. The subgrade drainage controls the moisture movement due to water table effect.

2.9.2.1 Water Table Effect

Where the road is in cutting or at ground level, it is important to prevent the water table from rising too close to formation level, since moisture content by capillary action can cause changes in sub-grade moisture content. It is considered that a stable subgrade can be maintained if the water table is kept at least one metre below formation level. Sub-soil drains running along the pavement at appropriate depths will achieve this.

Subsurface drainage system in the form of semi-perforated pipe, mechanically/ chemically pre-wrapped with nonwoven geotextile is used for dissipation of pore pressure and improve the cut slope stability. The function of subsurface drainage system is to collect the seepage water inside the soil mass and discharge to the nearest outlet point, which is the surface drain. For any filled-up embankment or steep slope or retaining structure, it is very important to have proper drainage system to improve the overall stability of the structure. The subsurface drainage system consists of 600 mm thick well graded granular fill material of Class –II as per Table No. 300-3 of MORTH specification or alternatively geosynthetic drain shall be used for collection of subsurface water and disposal to suitable outlets. The subsurface drain shall be provided at the toe of the embankment or retaining structure and also at intermediate heights for any taller structure at every 10 m height.

2.9.2.2 Moisture Movement between Berms/Shoulders and Subgrade

Changes in the moisture content of the road pavement and subgrade materials may take place as a result of the transfer of moisture to and from the soil in the road berms. The berm will normally have a higher moisture content than the subgrade in winter and a lower one in summer and therefore moisture will be transferred to the subgrade in winter and vice-versa in summer with clay subgrades. This will result in swelling and shrinkage of the subgrade along the carriageway edges with consequent differential rise and fall with respect to the road crown and in spells of prolonged drought, may give rise to longitudinal cracking along the road surface. A subsurface drain situated between the berm and the carriageway removes the point of weakness from the edge of carriageway to the outside of the shoulders where its effect is much less critical.

(i) Infiltration through Pavement

Most of the road surfaces are topped with open-graded bitumen premix carpet only and ingress of moisture through the porous surfacing may penetrate into the subgrade. If the pavement has surface cracks, the inflow through the pavement into the subgrade during rainy season will be much more and cause further deterioration of the pavement.

(ii) Due to Snow

Thawing of snow creates problem and the resultant water thereof shall be drained off the road from the nearest exits. These exits can be developed by cutting snow on the berm on valley side. A regular flow of this water will help in quick melting of snow also. Use of common salt, saw dust/sand is made to counter the problem posed by ice formation/frost. **Chapter 6** dealing with snow clearance gives more details.

(iii) A drainage blanket of selected filter material below the structural section of the pavement, facilitate the infiltration through the pavement, lower the water table and arrest moisture movement by capillary action from the soil all around. **Figs. 2.10, 2.11 & 2.12** indicate such arrangements. Subsurface drainage is also achieved by providing trenches filled with filter material, i.e., sand, gravel, etc. which drain off the underground water. As an alternative to conventional filter material, geo-textiles can also be used.

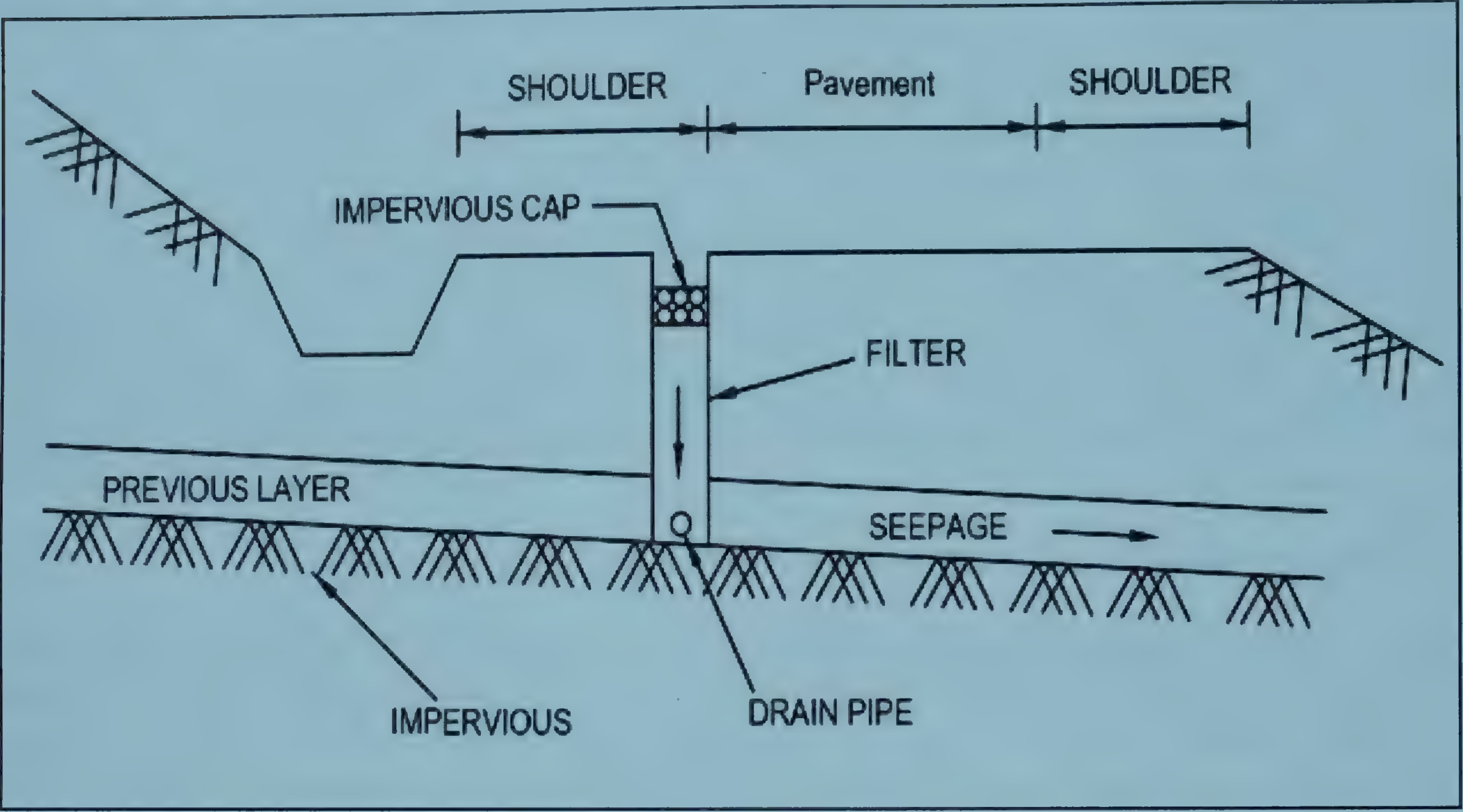

SHOULDER
Pavement
SHOULDER
IMPERVIOUS CAP
FILTER
PREVIOUS LAYER
SEEPAGE
IMPERVIOUS
DRAIN PIPE

Fig. 2.10 Sub-Grade Drainage

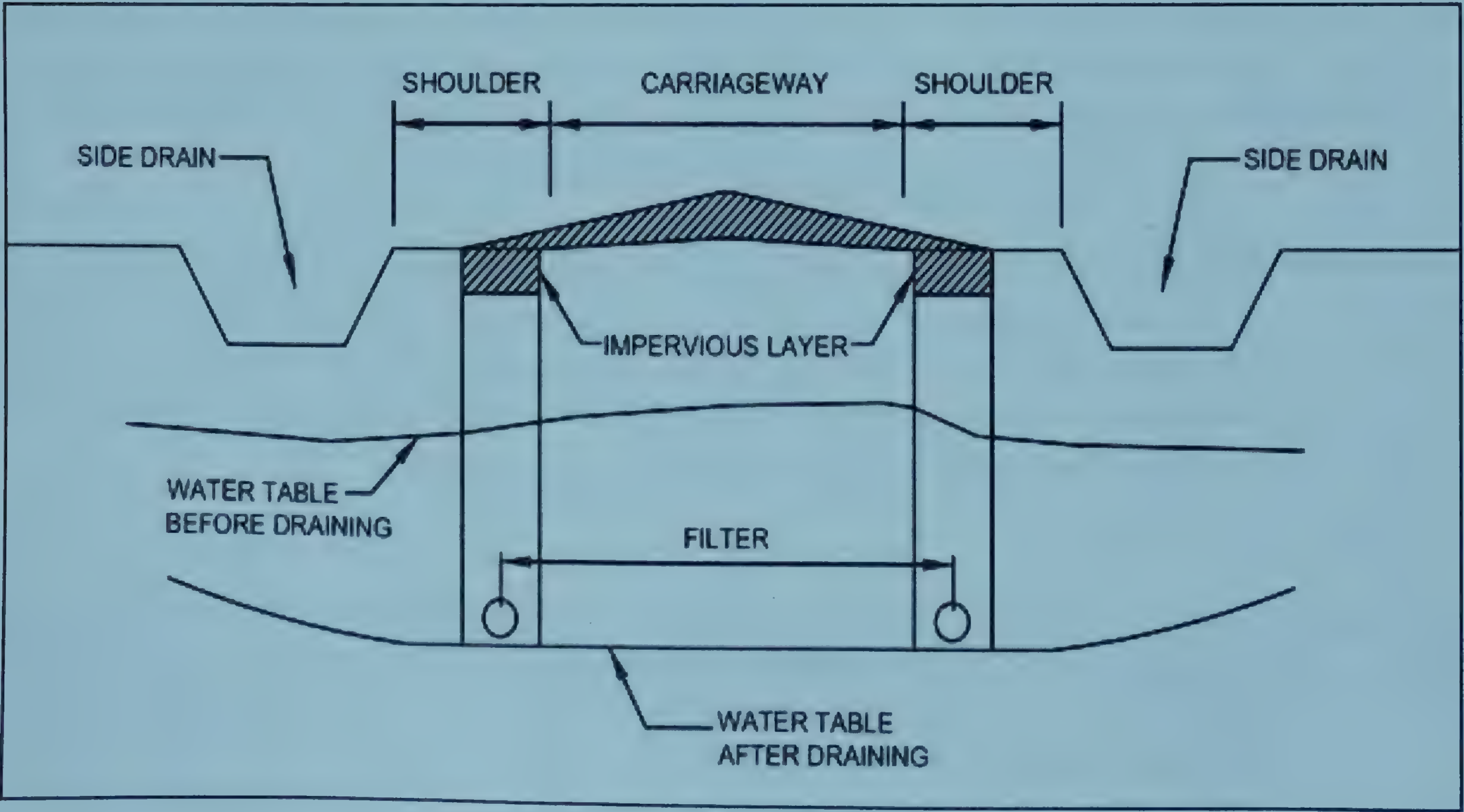

SHOULDER
CARRIAGEWAY
SHOULDER
SIDE DRAIN
SIDE DRAIN
IMPERVIOUS LAYER
WATER TABLE BEFORE DRAINING
FILTER
WATER TABLE AFTER DRAINING

Fig. 2.11 Lowering Water Table

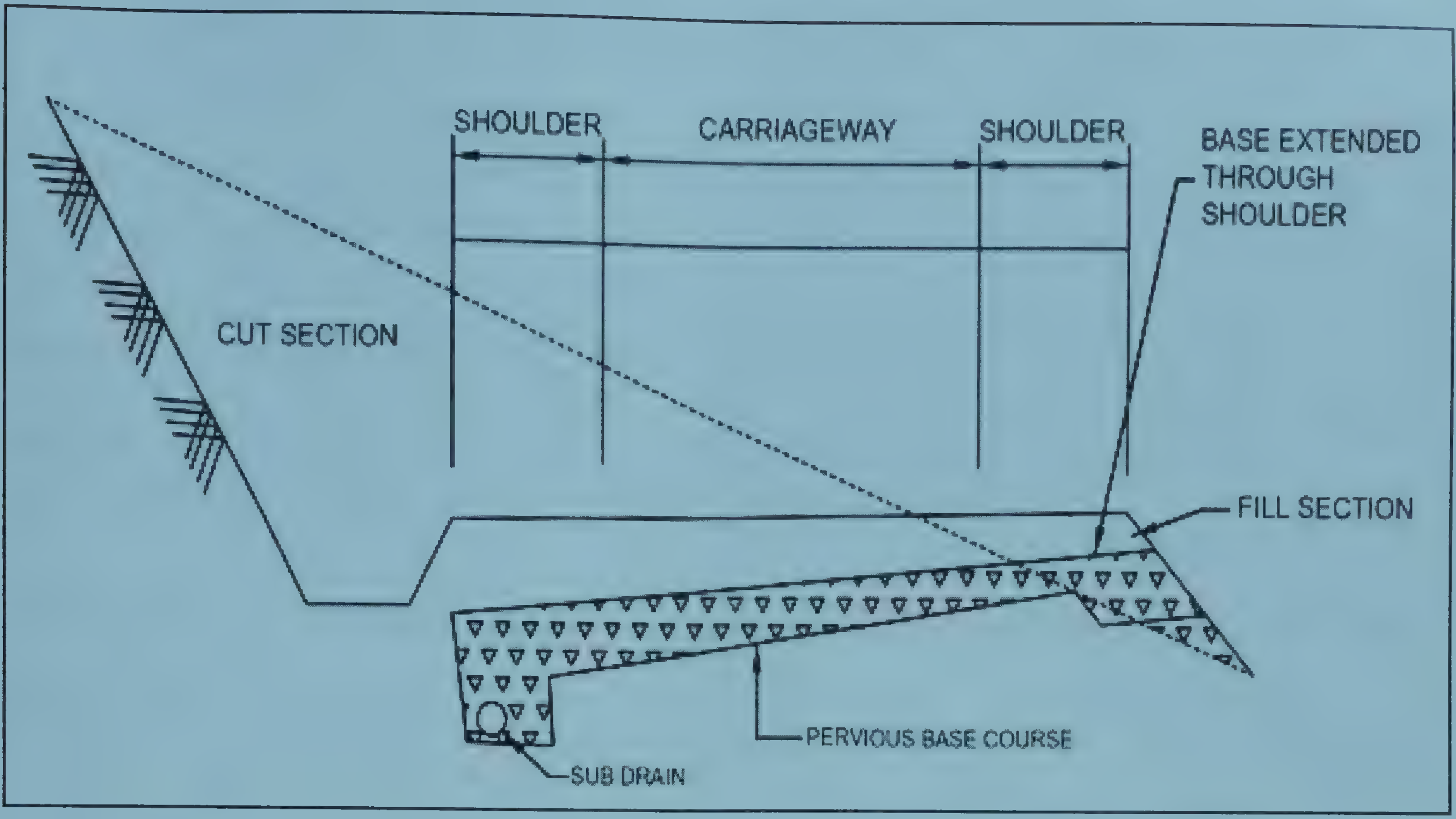


Fig. 2.12 Pavement Drainage

2.10 Cross-Drainage-Hydrological Considerations

2.10.1 Whenever streams have to cross the road, cross drainage structures shall be provided. Similarly, water from the side drains is taken across by these cross drains in order to divert the water away from the road to a water course or valley.

2.10.2 A variety of Cross-Drainage structures are possible. Those can be considered under two broad groups namely:

a) Crossings that are submersible, such as fords, paved clips, causeways, and submersible bridges.

b) Crossing that are not submersible, such as culverts, bridges and ferries.

Each type of crossing has an appropriate place for use.

2.10.3 The considerations in the proper choice of the type of crossing are:

a) Functional
  - i) Number of vehicles delayed.
  - ii) Length of time of each delay.
  - iii) Number of times per year these delays occur.

b) Technical
  - i) Nature and width of stream and flood flows – whether flashy or sustained.
  - ii) Velocity of flow and bed slope.
  - iii) Maximum and minimum depth of flow.
  - iv) Presence of floating debris, boulder movement on the bed etc.
  - v) Local materials and skills available.

c) Economical

  i) Cost of initial construction.

  ii) Cost of maintenance or reconstruction.

  iii) Cost of delays to vehicles (in the case of submersible crossings).

Normally experience and local practice will be highly helpful in the choice of the appropriate crossing. However, there can be overlapping cases suggesting more than one alternative. In such cases, where doubt exists, it would be worthwhile to evaluate alternatives taking all the above-mentioned aspects into account. For quick selection of promising alternatives, the guidelines given in **Table 2.1** will be helpful.

Table 2.1 Guidelines for the Choice of Cross Drainage Structures for Hill Roads

Sl. No.	Type of Structure	Locations where the structure will be found suitable
1.	Ford	Shallow non-perennial stream where maximum depth of flow does not exceed 1.6 m and the period of interruption at one stretch does not exceed 12 hours for ODRs and 24 hours for VRs in hilly terrain. Also, the total period of interruption in a year may not exceed 10 days for ODRs and 15 days for VRs. Suitable for roads in isolated areas carrying very low traffic. Also, for roads in a network where alternative route is available during the rainy season. Low in initial cost and ideal for crossing of men on foot and cattle.
2.	Paved dip (flush or low-level causeway)	Same as for Sl. No. 1 except that the traffic on the road may be somewhat higher.
3.	Vented Causeway	Shallow streams having permanent dry weather flow exceeding 0.6 m in depth. The same criterions indicated for Sl. No. 1 as regards interruption equally apply to this case also.
4.	Submersible bridge	In case where high level bridge is too expensive to construct.
5.	Culvert	This is a high level structure having length between abutments upto 6 m. Suitable for narrow streams.
6.	High level bridge	Ordinarily high level bridges are designed to cater for the maximum possible flood discharge. Situations warranting such bridges arc crossings of deep narrow streams or ravines in hilly terrain.
7.	Steel Equipment Bridges (Portable)	Portable steel bridges are quite easy and quick to construct even for emergent need.
8.	Suspension Bridges	Ideally suitable to bridge long and deep gaps in hilly terrain.
9.	Boat Ferry and Pontoon/boat bridges	In case of large streams where it is not economical to provide a bridge, ferry service or pontoon/boat bridge may be available.
10.	Other Crossings	Wire rope trolley may be used for remote and unimportant areas.

2.10.4 *Details of submersible types of cross-drainage structures are given below:*

a) Ford

Location for the ford is chosen at a place where the stream runs in shallow channel. A trench about 1 m wide and 1 to 1.2 m deep is dug on the bed of the stream along the downstream edge of the road. The trench is then filled with stones in wire crates up to the level of the road. As an alternative, a masonry (stone or brick in cement mortar 1:4) wall could be built along the down-stream edge to retain the road in position. The road surface is formed by levelling the stream bed with gravel. After one or two seasons, fines transported by the stream will fill in the voids in the gravel surface, leaving a satisfactory stream crossing. Details of a typical ford are illustrated in **Fig. 2.13.**

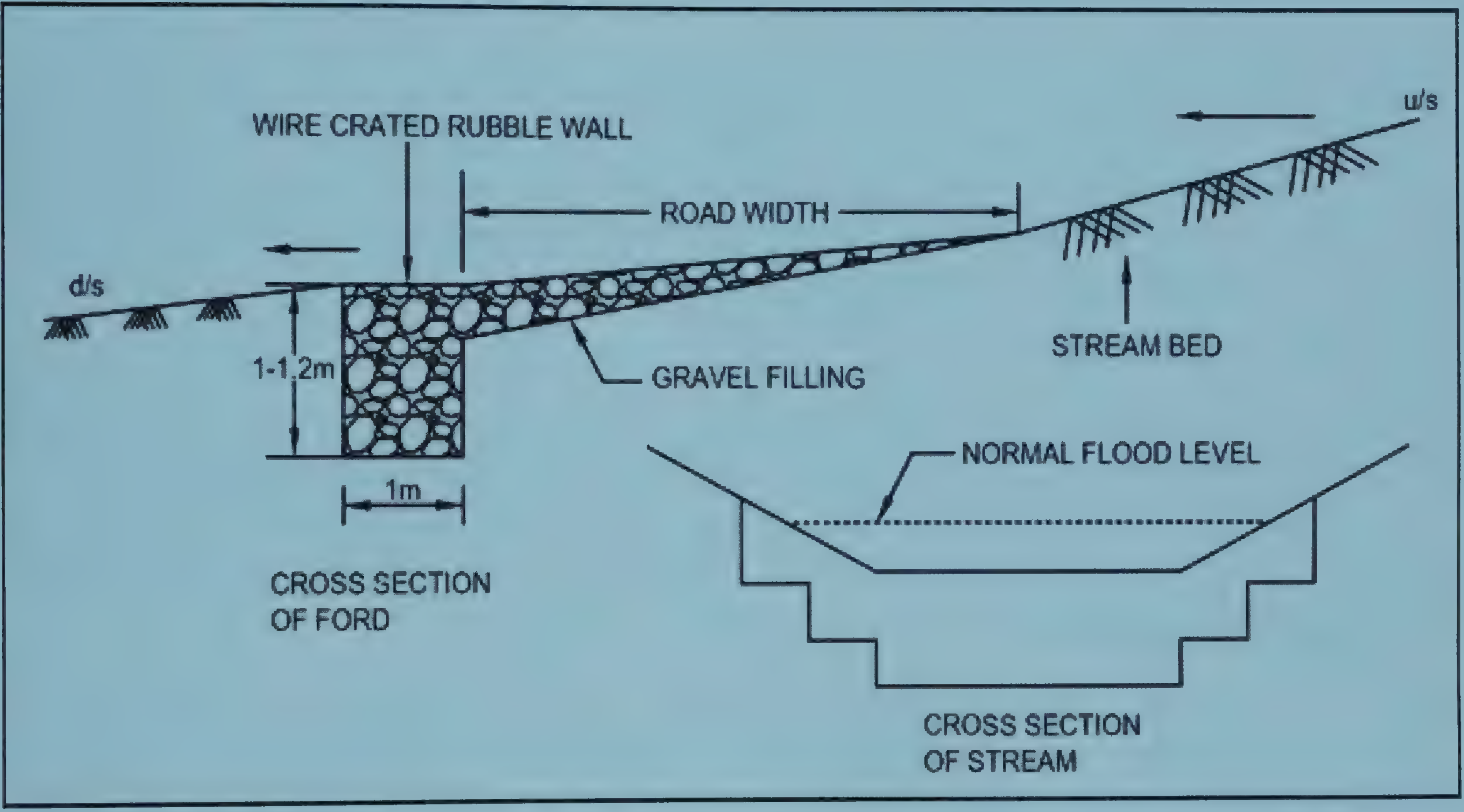


Fig. 2.13 Ford

2.10.5 *Details of non-submersible drainage structures-(Culverts) are given below:*

2.10.5.1 It is a bridge having a length of six meters or less between the face of abutments or extreme vent-way boundaries and measured at right angles thereto. Generally, 8 to 10 culverts/ or as per site requirement shall be provided per kilometer length of Hill Road for efficient drainage and at every small rivulet. The vent should be about 1.0 m x 1.5 m or as per design so as to afford ample space for the maintenance staff to clean them before and after the rainy season. Blockage and choking of these vents can cause serious damage to the road structure as water spills over to the road.

Adequate protective works are required at the discharge point upto the natural drainage channel level which shall be preferably be in the form of catch pit stepped guide walls, chutes and Apron to dissipate the kinetic energy of the discharged water outfall.

2.10.5.2 Culverts may be any one of the following types:

a) Pipe Culvert

b) Arch Culvert

c) Slab Culvert

d) Box/Precast Segmental Box Culvert

(a) Pipe Culvert

They are provided when discharge of stream is small or when sufficient headway is not available. Usually, one or more pipes of diameter not less than 90 cm, preferably 100 cm - 120 cm, are placed side by side. Their exact number and diameter depends upon the discharge and height of - bank. These pipes can be made of masonry, stoneware, or cement concrete. A concrete bedding shall also be given below the pipes and earth of sufficient thickness on the top to protect the pipe and their joints. As far as possible the gradient of the pipe should not be flatter than 1 in 30. As the pipe culverts need a cushion of 60 cm or so, these culverts may be adopted only at locations where it is suitable. A Typical sketch is given in **Fig. 2.14.**

(b) Arch Culvert

This consists of abutments, wing walls, arch, parapets and the foundations. The construction materials, commonly used, are stone masonry or concrete. Floor and curtain wall may or may not be provided depending upon the nature of foundation soil and velocity of water flow. A typical sketch is given in **Fig.2.15.**

(C) Slab Culvert

A slab culvert consists of RCC slab with or without beams or a stone slab, with or without steel girders to cover the span across the abutments and piers. The deck slab shall be designed as one way slab. A typical sketch is given in **Fig. 2.16.**

(d) Box/Precast Segmental Box Culvert

A Box Culvert is a reinforced concrete culvert of rectangular cross section, with RCC base slab, abutment walls and slabs connected monolithic. They are provided with or without earth cushion on top slab, in a single box or multiple box cell placed side by side.

In order to increase the pace of construction & without making the provision of traffic diversion route, the provision of pre-cast segmental box culverts is gaining popularity in mountainous/Hilly region on large scale. A brief description on its construction methodology based on experience in Chardham Project is placed at **Appendix-2.1.**

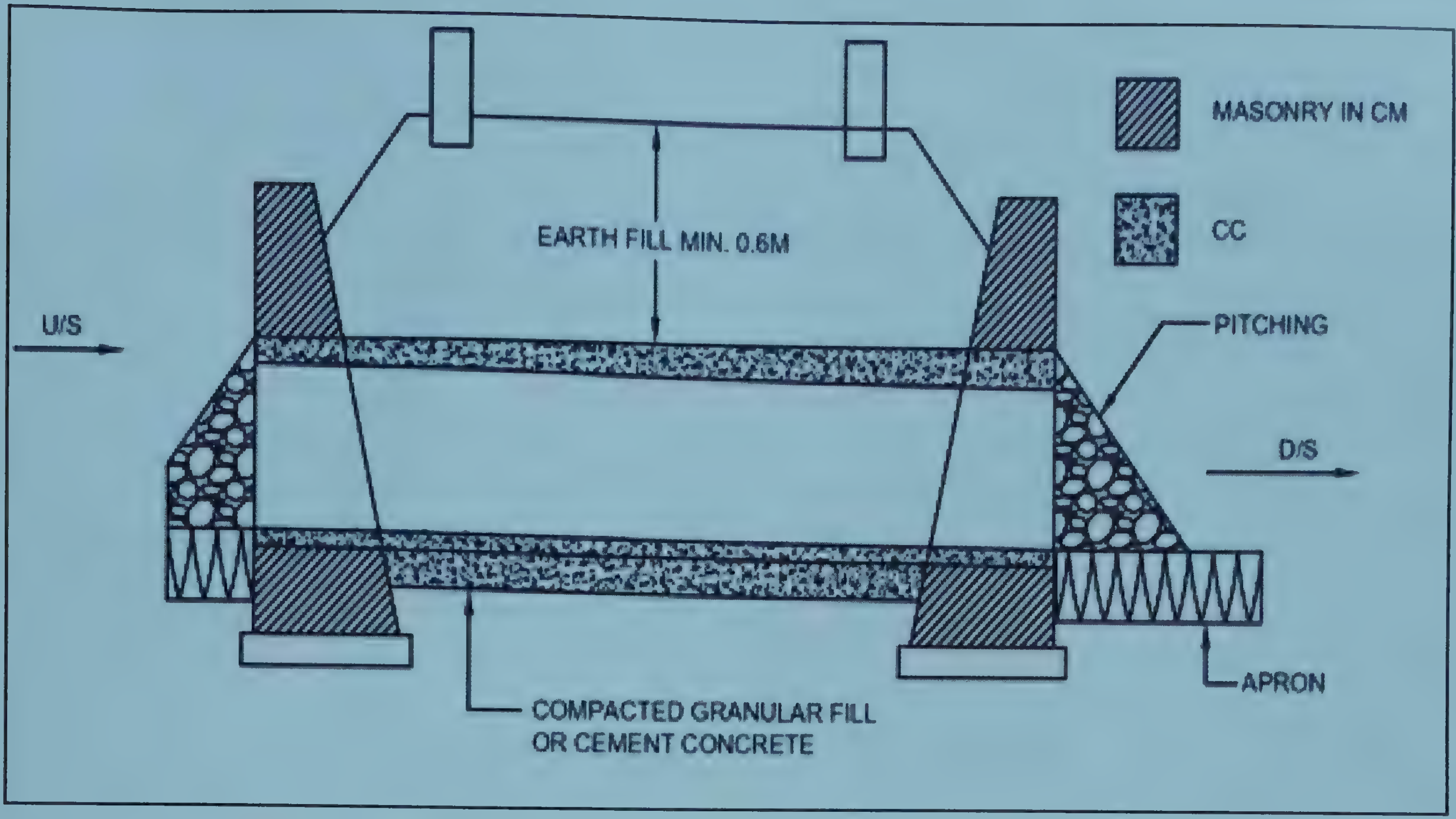

MASONRY IN CM
CC
EARTH FILL MIN. 0.6M
U/S
PITCHING
D/S
APRON
COMPACTED GRANULAR FILL
OR CEMENT CONCRETE

Fig. 2.14 Typical Culvert in Embankment - Pipe Culvert

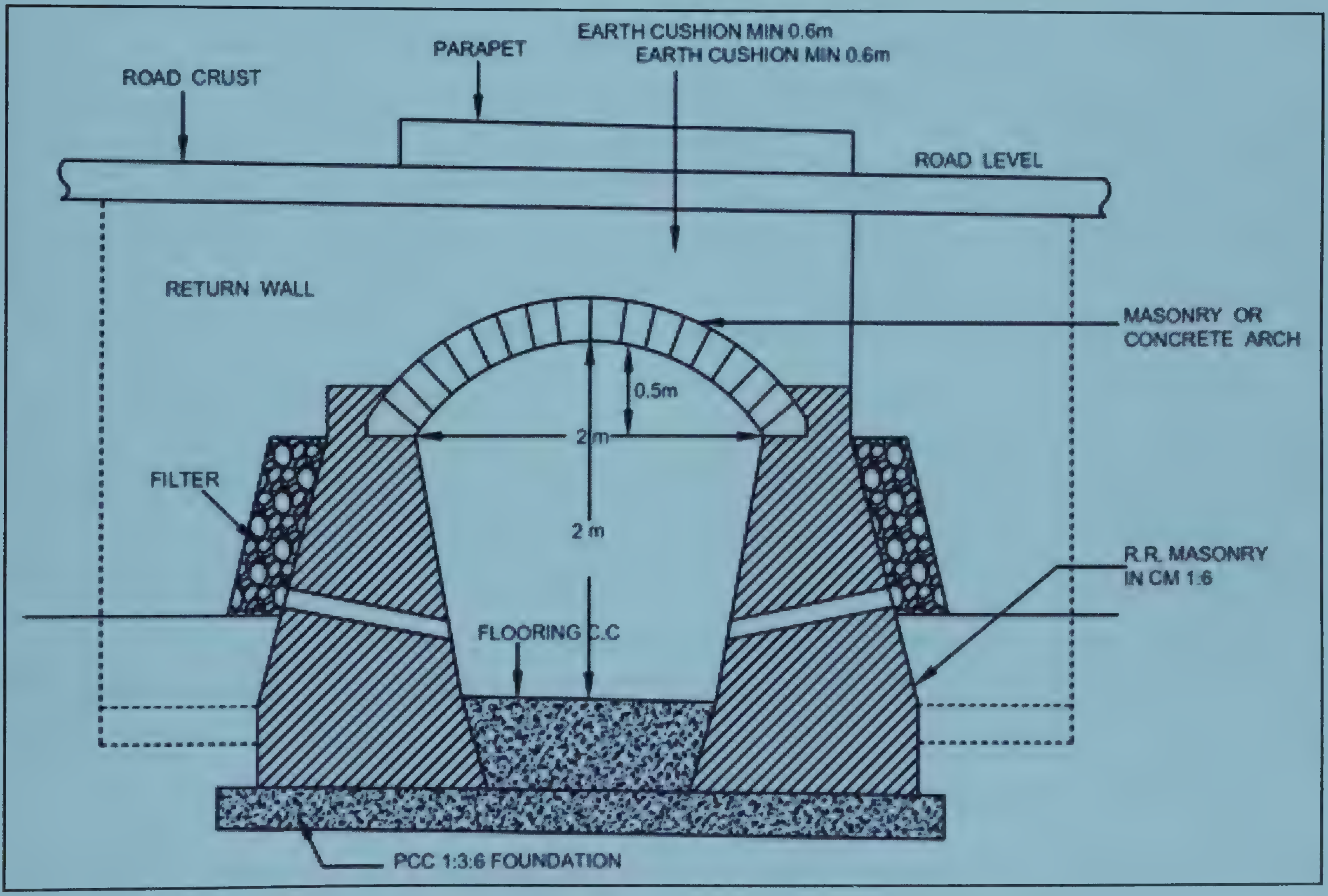

EARTH CUSHION MIN 0.6m
PARAPET
EARTH CUSHION MIN 0.6m
ROAD CRUST
ROAD LEVEL
RETURN WALL
MASONRY OR
CONCRETE ARCH
0.5m
2 m
FILTER
2 m
R.R. MASONRY
IN CM 1:6
FLOORING C.C
PCC 1:3:6 FOUNDATION

Fig. 2.15 Typical 2 m x 2 m Arch Culvert (Section)

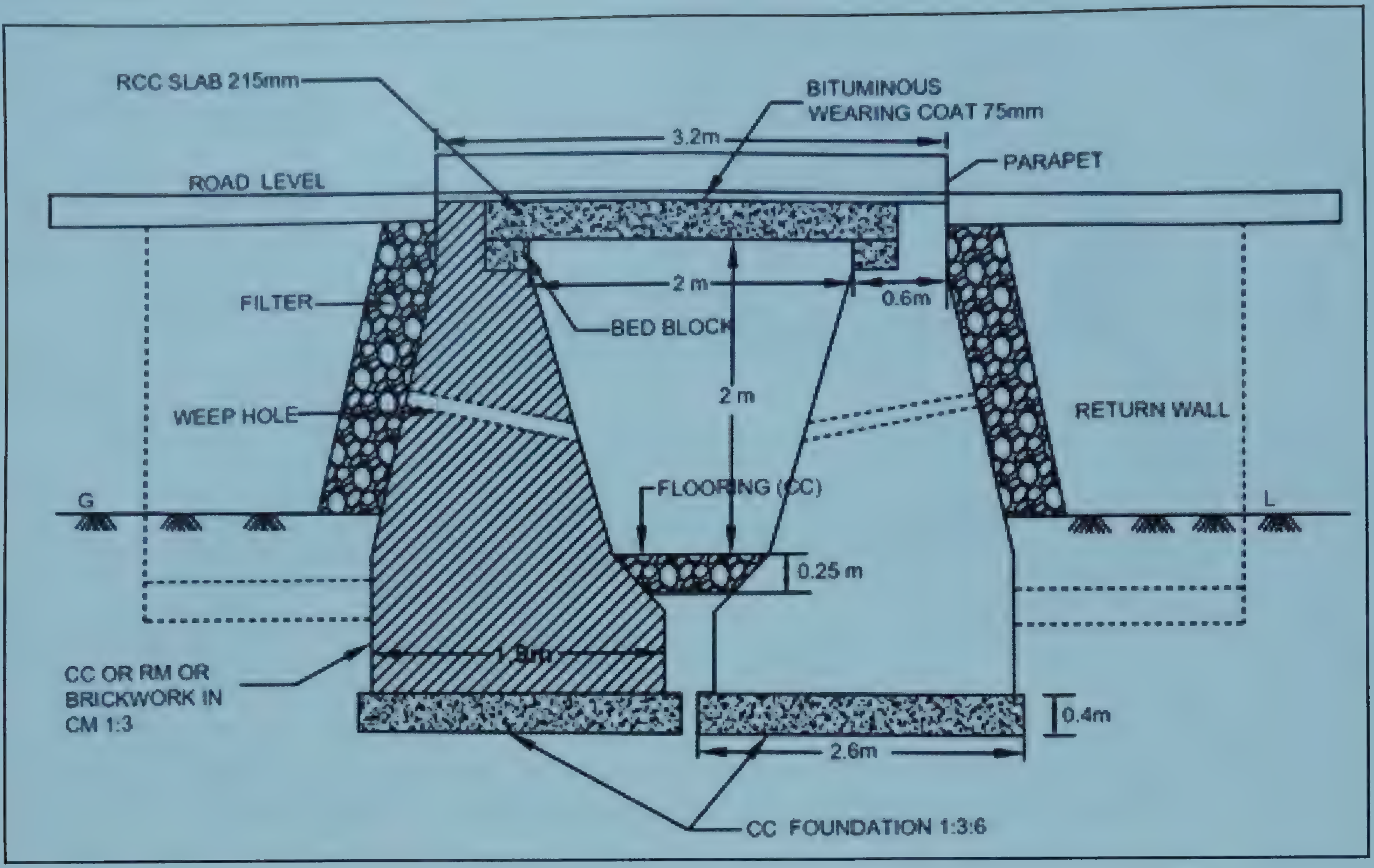


Fig. 2.16 Typical RCC Slab Culvert 2 m x 2 m (Section)

2.10.5.3 In isolated areas, in locations where provision of a motor-able bridge may not be economically feasible and where a crossing is required only for people and cattle, provision of foot bridges will be an expedient solution. Foot bridges may vary in shape and details of construction depending on the local materials available. A variety of materials, like tree trunks, wooden sections, R. S. Joists or used rails can be used for the main beams over which wooden deck could be constructed. In areas where bamboo is available in plenty, two to four pieces of bamboo can be clamped or fixed together to act as a single beam for span up to 3 m.

The substructure may consist of timber piles of trestles depending on local conditions. Pile type supports shall be used when site conditions are affected by deep water or swift current causing scour, low bearing capacity soil overlaying rock, or un-consolidated soil with low bearing capacity. For spans greater than 5 m, a double row of piles/trestles as per design shall be used for a pier.

Considering the effect of extracting timber in denuding forests and adverse environmental impact, timber bridges shall be avoided unless timber is available from trees cut as part of road formation work.

2.10.6 *High Level Bridges*

Bridges are structures facilitating a communication route for carrying road traffic or other moving loads over a depression or obstruction such as river, stream, channel, road or railway. Bridges are classified as major or minor on following criteria:

a) Bridges with waterway of more than 60 m between the two abutments are generally termed as major bridges, whereas those with waterways less than 60 m and more than 6 m are termed as minor bridges. Since the bridge structures are of vital importance for communication system, more so in hilly areas where alternative routes are generally not available, the design and construction of the bridges needs special attention. I.R.C. Bridge Codes covering subsurface investigations, design and execution already exist and the same should be used.

b) Depending upon the merits of each case, the foundations of the bridges in hilly areas may be either open foundations or on wells. Similarly, the superstructure may be in R.C.C., Pre-stressed concrete, Timber, Steel or some composite construction. The final choice should, however, be arrived at most judiciously, keeping in view the economy and practical feasibility. Detailed field studies and inspection by senior engineers are very necessary. However special points relating to hilly areas are given below:

  i.) While making temporary crossing on a river the same be built on a second best site, the best site being kept for construction of the permanent bridge.

  ii.) Since the bed level of the nallahs (stream) are steep, cross sections should be taken at appropriate short intervals so as to cover all topographical details.

  iii.) Since the flow of water in hill streams is very fast and in most cases, they carry boulders and also construction of diversions is not easily feasible, it may be preferable to provide single span bridges depending on economics and feasibility.

  iv.) In case of suspension bridges, the safety of the bridge depends upon the safety of the anchor block. The geology of the hill below the anchor, shall be very carefully studied.

2.11 Optical Fiber Cable (OFC) Duct

In Mountainous/Hilly region it has become common practice to lay the OF cables on hill side after cutting the toe of hills. Further, different telecom operators lay their OF cables at different time depending upon launch of their services. This results into damages of hill toe, blocking the road side drains etc. In order to address this issue. It may be more appropriate to provide OFC duct in all hill road projects. Based on practice to lay OFC duct in Chardham Project, a brief details regarding laying of OFC duct is enclosed at **Appendix-2.2.**

CHAPTER 3

SLOPE STABILITY, LAND SLIDE & ROCK SLOPE – INVESTIGATION AND ANALYSIS

3.1 General

In hilly terrains, landslide phenomena is very common as well as complex in nature. Type of slopes are of varied nature which are further triggered off due to rainfall and development of pore water pressure on account of in appropriate drainage facilities etc. Accordingly, a detailed investigation and analysis before adopting the rehabilitation methodology plays a vital role to ensure the sustainability of slopes' stability in hilly region.

3.1.1 *Classification of Slope Movements*

3.1.1.1 According to Ward (1945) classification of the types of slope failure is necessary for an engineer to enable him to distinguish and recognize the different phenomena for purposes of design and to take appropriate remedial or safety measure where necessary.

3.1.1.2 Over the years, different systems of landslide classification have been evolved based on the mode and rate of the movement, shape of the slide surface, type of material involved and a number of other factors. From the engineering-geological point of view, Terzaghi's (1950) grouping of landslides was based on the physical properties of the rocks involved. Sharpe (1938) classified sliding movements according to the material displaced and the type and rate of movement and studied the relationships between mass movements and geomorphological cycles and climatic factors. Varnes (1978) classification, establishes five principal types of mass movements and adds a sixth to accommodate landslides which combine characteristics of several principal types as given in **Table 3.1** The same is summarized and explained below:

a) Falls: The loosened rock mass is in free fall for the greater part of the distance of movement.

b) Topples: The rock mass overturns about a point below its center of gravity

c) Slides:

   i). Rotational: The rock mass moves about a point above its center of gravity.

   ii). Translational**:** The rock mass moves predominantly along more or less planar or gently undulating surfaces.

d) Lateral spreads: Lateral extension movements occur in a fractured mass.

e) Flows:

   i). In bedrock: These include continuous deformations, surficial and deep creep, involving extremely slow and generally non-accelerating differential movements among relatively intact units.

   ii). In Soil: Movement occurs within a displaced mass, the form or apparent distribution of velocities of which resembles to that of a viscous fluid.

f) Complex Slides: Landslides exhibiting a combination of two or more of the five Principal types of movements as listed under **Table 3.1;**

Table 3.1 Classification of Slides (Varnes)

Type of Material				
Type of Movement		**Engineering Soils**		
		Predominantly Fine	**Predominantly Coarse**	**Bedrock**
Falls		Earth Fall	Debris Fall	Rock Fall
Topples		Earth Topple	Debris Topple	Rock Topple
Slides (rotational)	Few Units	Earth Slump	Debris Slump	Rock Slump
Slides (Translational)	Many Units	Earth Block Slide	Debris Block Slide	Rock Block Slide
		Earth Slide	Debris Slide	Rock Slide
Lateral Spreads		Earth Spread	Debris Spread	Rock Spread
Flows		Earth Flow	Debris Flow	Rock Flow
		(Soil Creep)		(Deep Creep)
Complex		Combination of two or more Principal Types of Movement		

3.1.1.3 The workable classification mentioned above provide some general directions for investigation and the selection of preventive or remedial measures for each established group of slope movements.

The main types of slides under this classification are illustrated in **Fig. 3.1**

3.2 Causes of Slope Movements

Terzaghi (1950) summarized the processes leading to landslides in his classic paper on the mechanics of landslides. In general, the causative factors are divided into those conditions that exist in a slope such as topography, lithology and structural features, and those conditions that may produce a change, such as excavations, seismic events and variations in ground water level. The following are the important conditions that cause slopes to become unstable and factors that trigger the movements.

3.2.1 *Geological Factors*

The type and nature of geological formation plays a vital role in determining the degree of stability of hill slopes. The composition and the type of the rocks, orientation of bedding planes and joints, the presence of faults and folds play a dominant role in determining the degree of stability. The dip of the beds in particular is an important and controlling factor. If the dip is such that the bedding planes are inclined towards the face of the slope, stability problems are likely to arise. Frequent and open joints also lead to instability.

Depending upon the orientation of bedding planes and Joints with respect to the hill face, different types of instabilities can arise namely falls, slides or topples. If the slope contains many tension cracks it is an Indication of distress being experienced by the slope formation. If bedding planes are filled with gouge material, stability is likely to suffer. Wherever the hill face is covered with considerable amount of debris or soil, failures may be restricted within the zone of the debris or may involve both the distressed rock as well as the overlying debris.

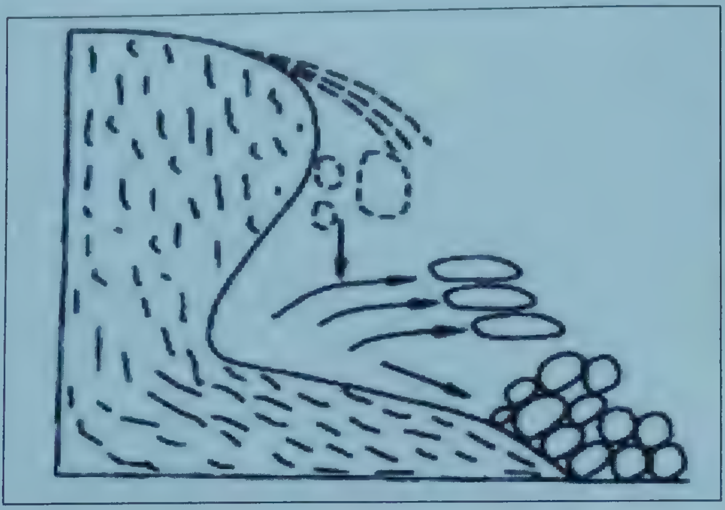
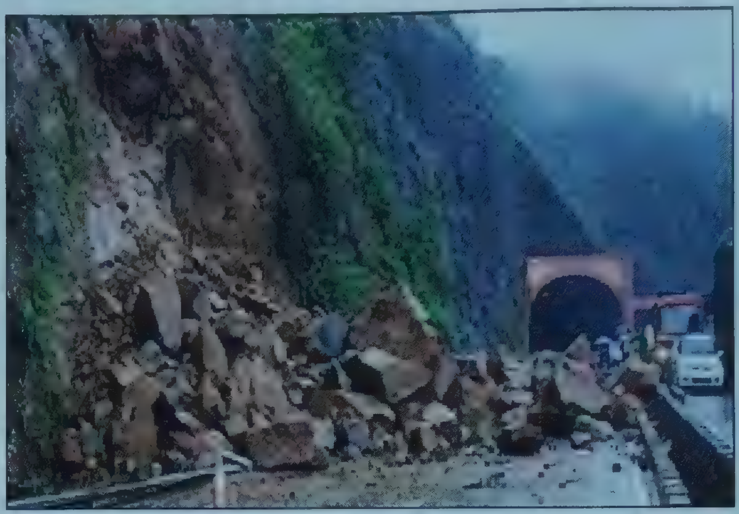
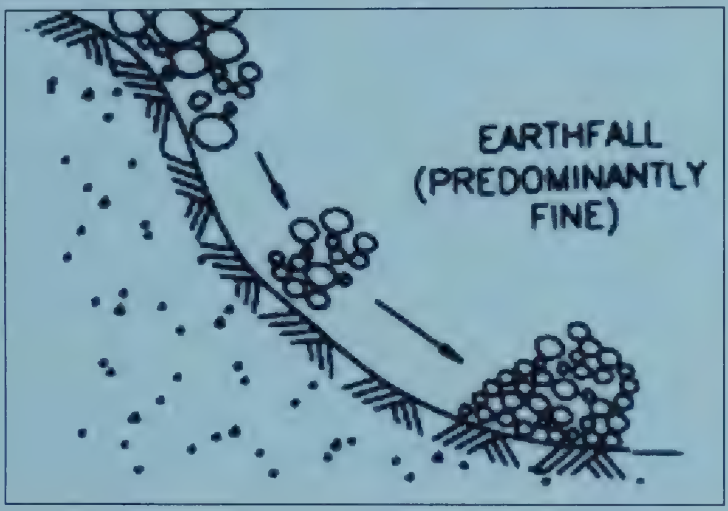
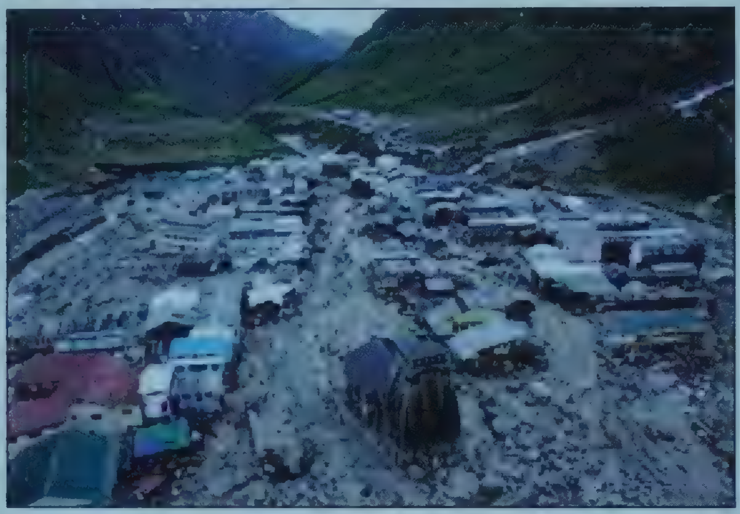
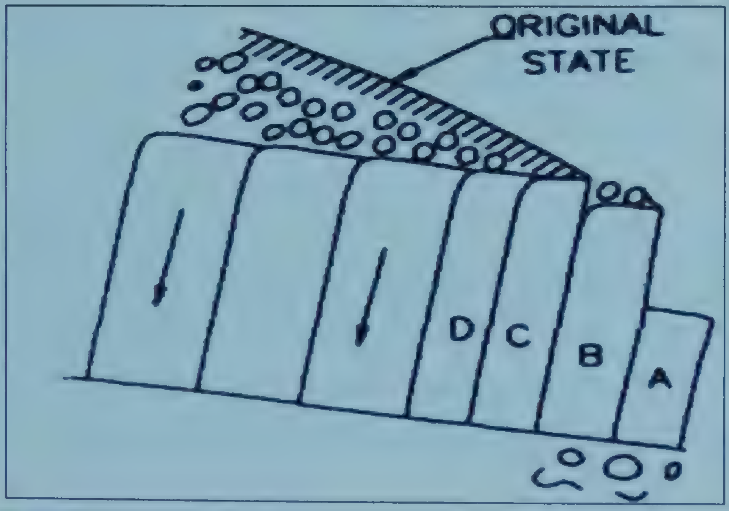
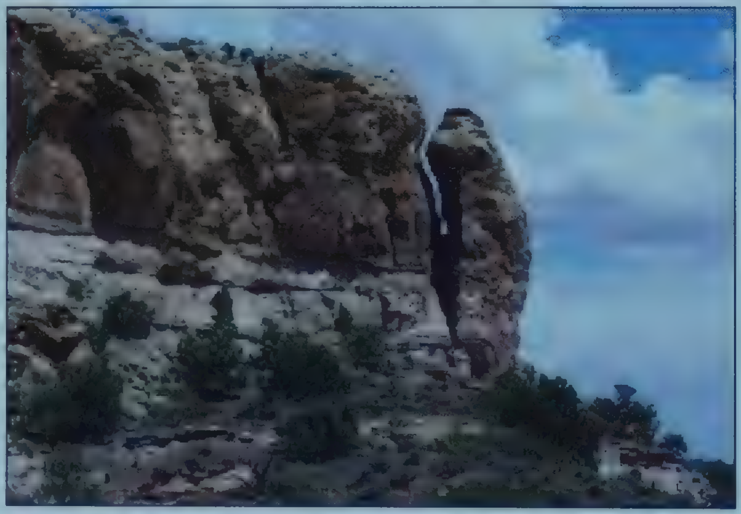
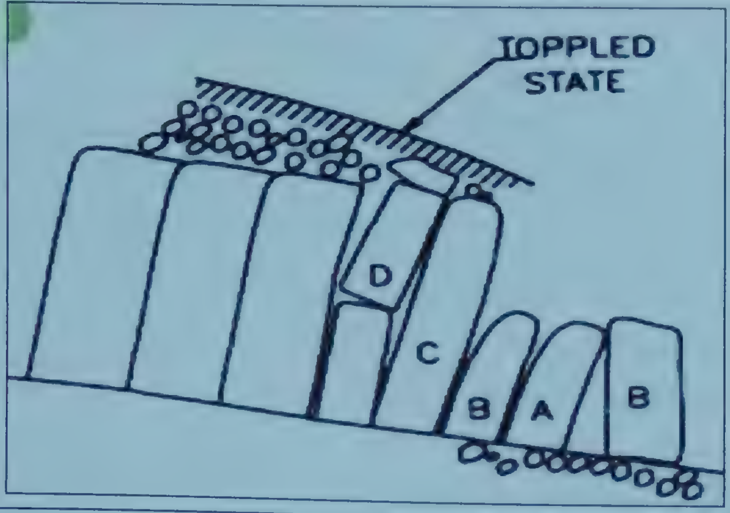
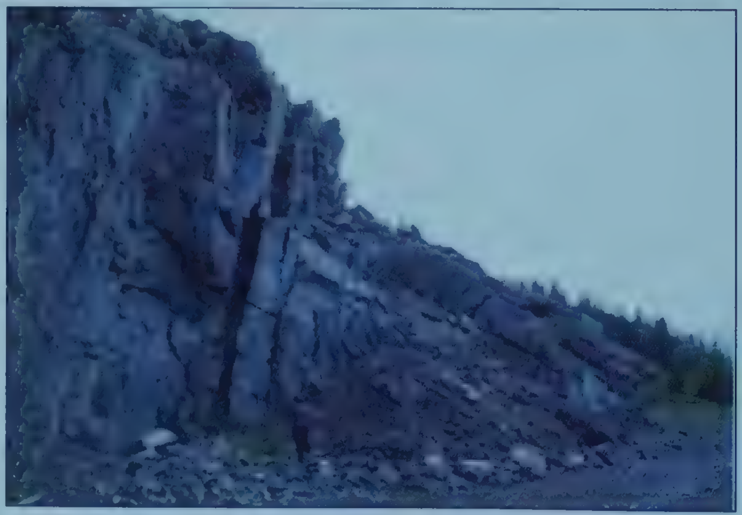
Rock fall		
Debris flow	 EARTHFALL (PREDOMINANTLY FINE)	
Rock Topple	 ORIGINAL STATE D C B A	
	 TOPPLED STATE D C B A B	

Fig. 3.1 Classification of Slides (Cont.)

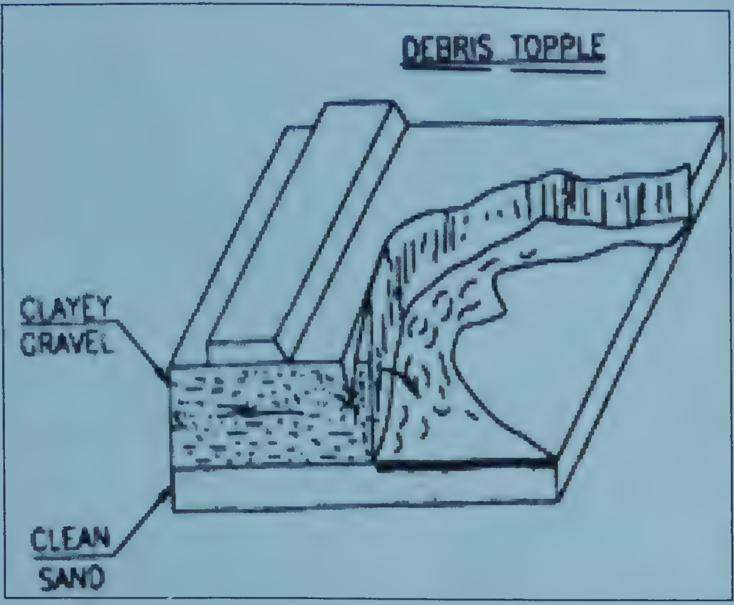
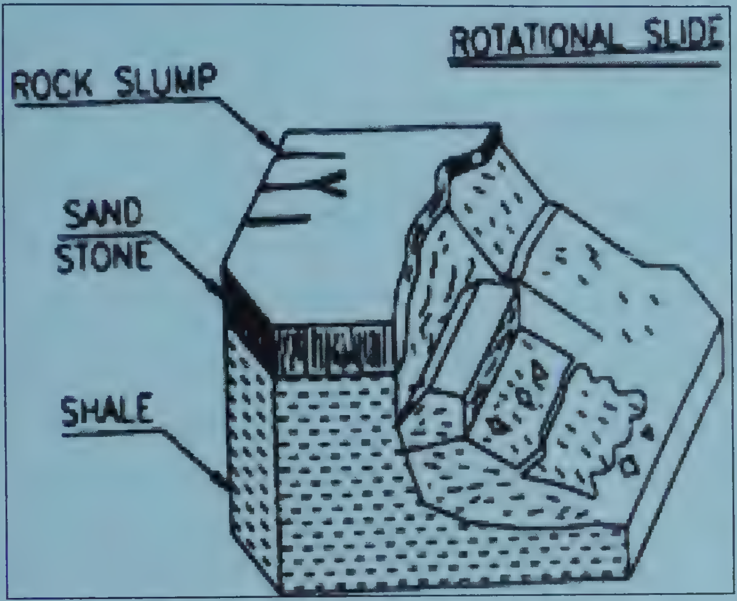
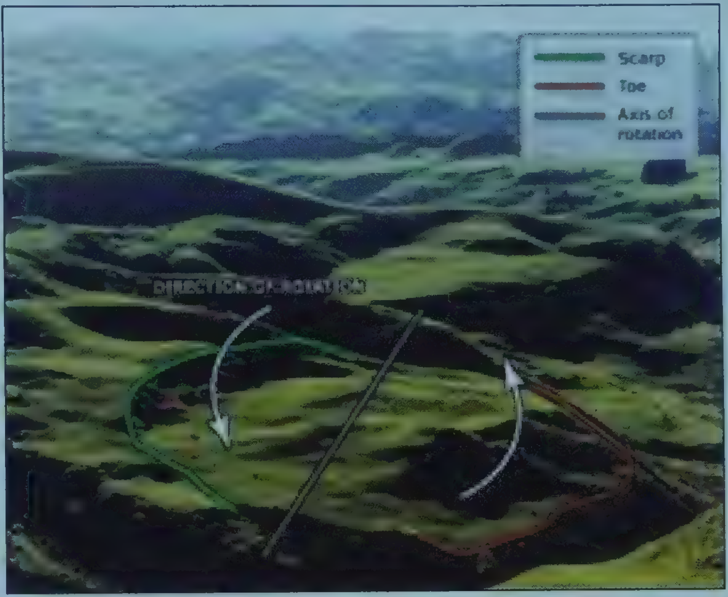
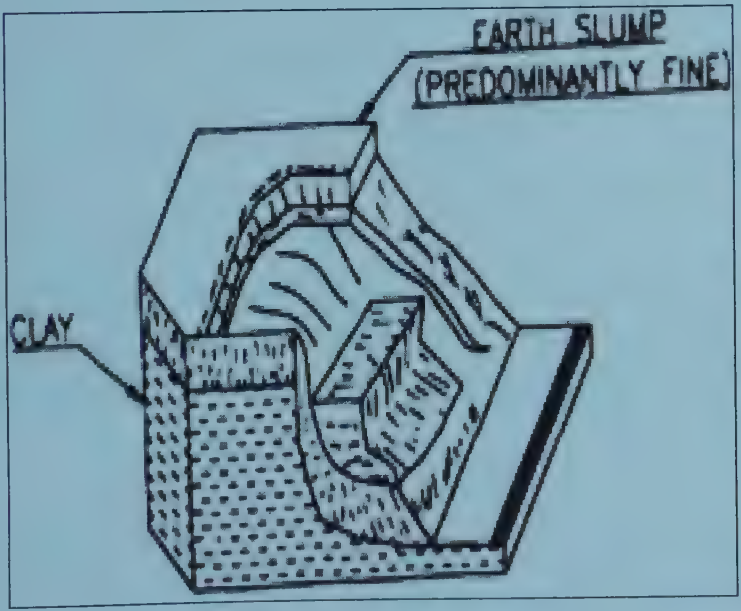
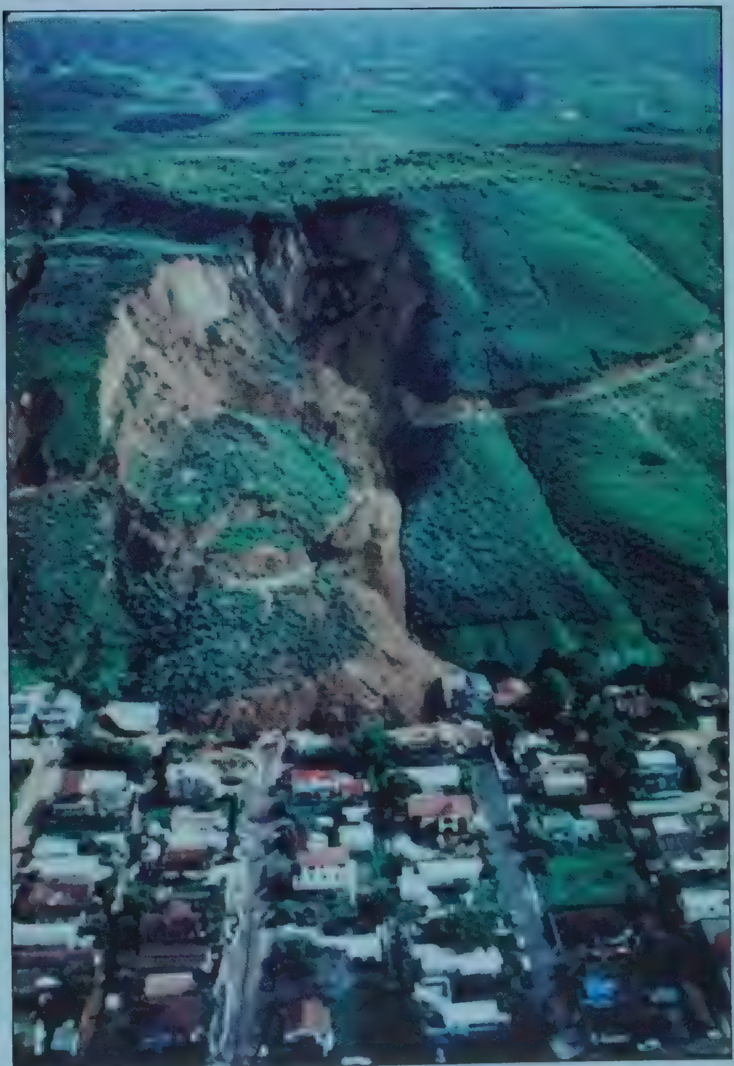
Debris Topple	 DEBRIS TOPPLE CLAYEY GRAVEL CLEAN SAND	
Rotational Slide	 ROTATIONAL SLIDE ROCK SLUMP SAND STONE SHALE	 Scarp Toe Axis of rotation DIRECTION OF ROTATION
Earth Slump	 EARTH SLUMP (PREDOMINANTLY FINE) CLAY	

Fig. 3.1 Classification of Slides (Cont.)

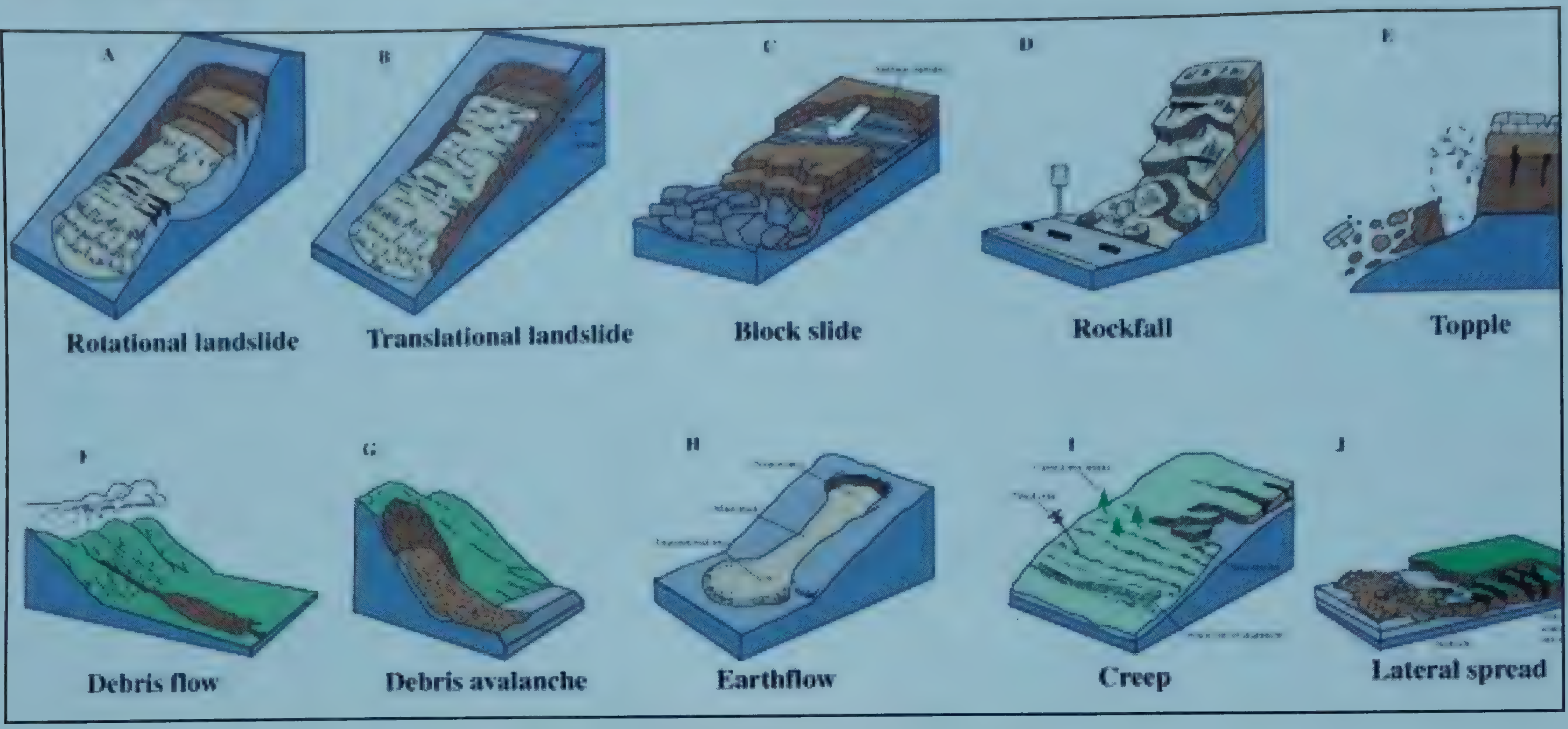


Fig. 3.1 Classification of Slides

3.2.2 *Change in the Slope Gradient*

A progressive increase in the slope angle due to undermining of the foot of slope by stream erosion or by excavation may result in a landslide. The angle of slope is increased due to previous rock fall, slide, subsidence or large-scale faulting. An increase in slope gradient causes a change in the internal stress of the rock mass and equilibrium conditions may be disturbed by such Increases in the stress.

3.2.3 *Surcharge*

The surcharge from natural causes may be due to rain, snow, accumulation of talus over-riding landslide materials, collapse of accumulated volcanic materials and vegetation etc. The surcharge may also be due to construction activity like fills and spoil heaps, weight of buildings and other structures. This produces an increase in the shear stresses and pore-water pressure in clayey soils, which result in decreased shear strength.

3.2.4 *Shocks and Vibrations*

Vibrations from blasting, machinery and earthquakes including minor tremors may trigger a landslide due to an increase in the shear stress and a decrease in the shear strength. In saturated fine sands and sensitive clays, vibrations may result in a sudden liquefaction of the soil.

3.2.5 *Changes due to Weathering*

Mechanical weathering such as softening of fissured clays, physical disintegration of granular rocks and chemical alterations such as hydration and ion exchange in clays, influence of seasonal and diurnal fluctuations of temperatures, freeze thaw cycles, generally result in the deterioration of the strength characteristics of slope forming materials, thereby increasing the risk of slope instability.

3.2.6 *Influence of Developmental Activities*

Increased pace of developmental activities in the hill areas have generally resulted in increased incidence of landslides. Slope cutting for roads, housing etc. and denudation of hill due to clearing of forests, mining activities etc., have had adverse effects on the stability of hill slopes. However, with adequate planning such problems can be avoided and where necessary suitable protective measures taken to preserve the hill slope stability.

3.2.7 *Water/Pore Water Pressure*

Water in the form of storm, surface runoff, subsurface water, flood or in combination is also one of the major triggering factors for causing or initiating land slide. Hence, any construction activity without designing an effective drainage system for the zone of influence, can cause land slide. Development of pore-water pressure also causes landslide; hence suitable subsurface drainage arrangement is vital for long term performance of any hill slope. The hill toe cutting/erosion during flood/surface runoff due to inadequate protection against damage of toe structure is also one of the major factor for landslide.

3.3 Landslide Studies and Investigations

Investigation and study of landslides broadly comprises of field and laboratory Investigations. Both geological and geotechnical aspects, in the broad sense of the terms, need to be studied. The objective of these studies is to collect data for the evaluation of the stability of the slope, determine the conditions under which failure may occur and base the remedial measures on a rational footing.

3.3.1 *Field Investigations*

Field investigations may be divided into five stages:

a. Topographical Mapping of the area

b. Geological and geomorphological investigations

c. Hydrological investigation

d. Geophysical

e. Geotechnical investigation

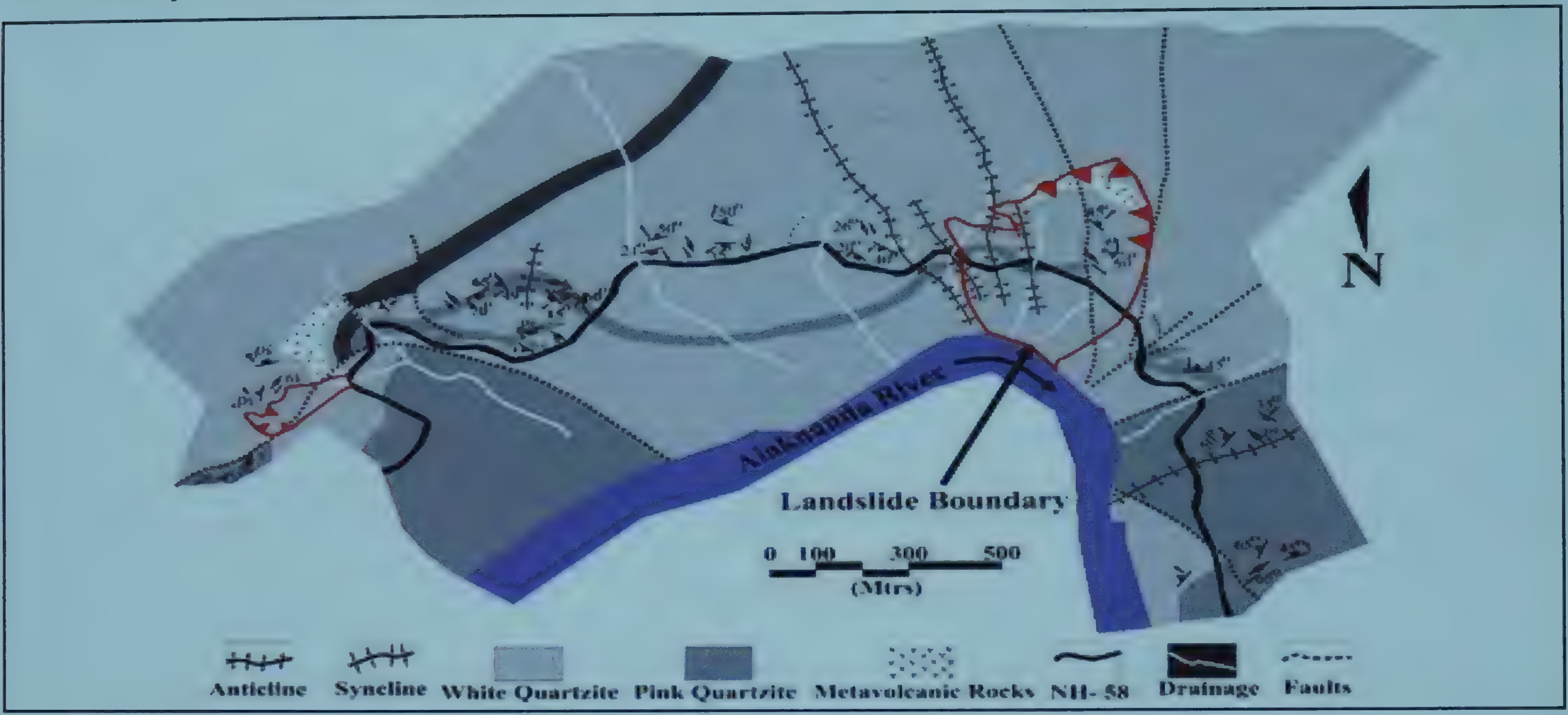
3.3.1.1 Topographical Mapping of the Area

The slide area should be mapped in detail. Field maps should be prepared giving the plan of the affected area and typical cross-sections, which can be used for stability analysis. The topography may be determined by aerial surveys (photogrammetry) which provides an overall view of the site features. It shall also be complemented with a detailed survey using drone, LiDAR (Light Detection and Ranging) and other remote sensing techniques which can generate contour map (3D) and sections which is accurate, cost and time effective in providing the current ground conditions. From the survey general observations should be made concerning the condition of the slope, covering such aspects as the extent and nature of vegetation cover, surface run off characteristics, presence of springs unfavorable ground conditions against construction, operation & maintenance including fractured/sheared zones, faults, steep slopes, landslides etc. Erosion of the toe and tension cracks in the crown area may be observed in detail.

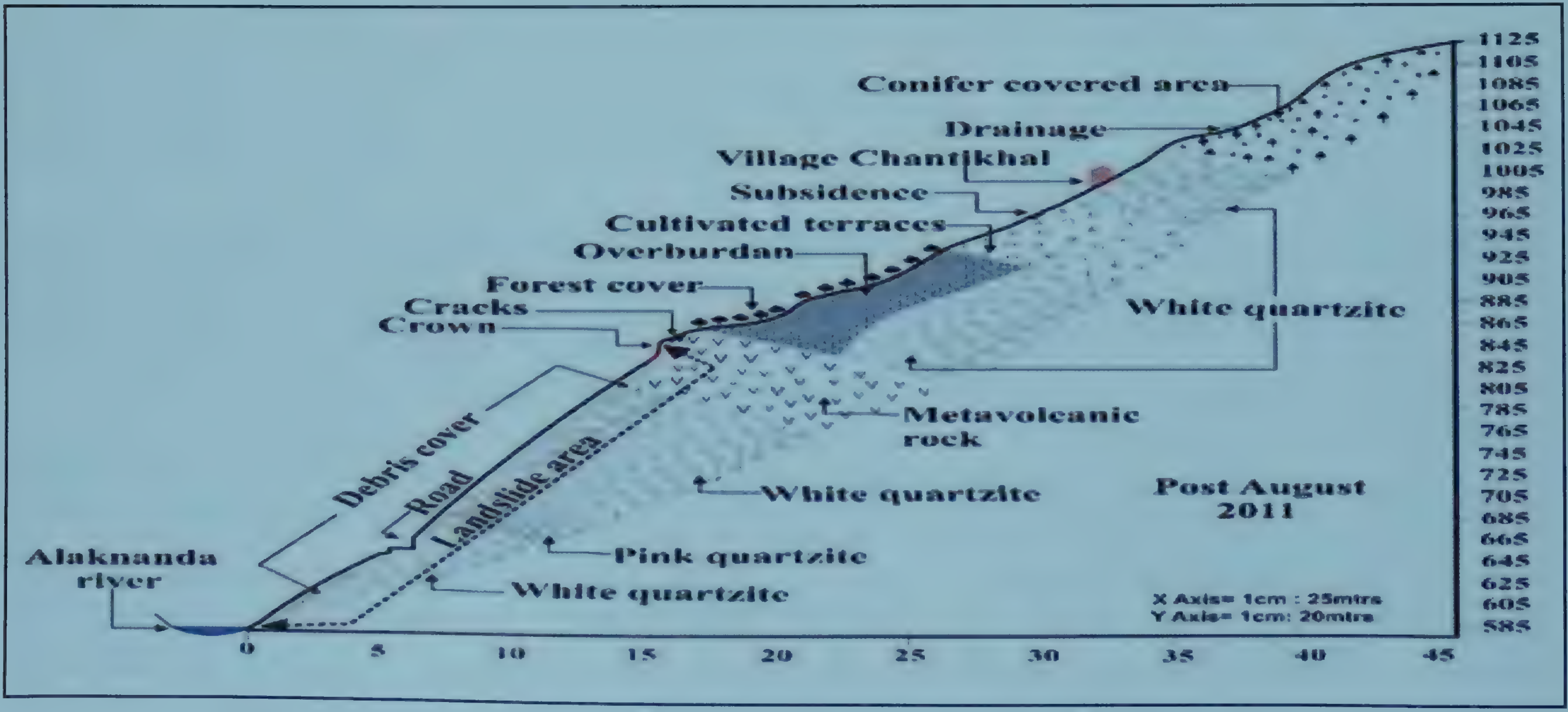
Topo-sheets of the area, design drawings and construction records from any previous structure at site (if available) should be studied as a part of the field investigation. Any signs or evidences for locating surfaces of failure should be carefully taken note of. Data concerning rainfall and intensity should be obtained as a part of field investigation. For further information on the subject, reference may be made to IRC:SP:106

3.3.1.2 Geological and Geomorphological Mapping

Geological map of the area, if available, should be studied carefully: Plan of the landslide area must be prepared incorporating geological data. Structural geological features such as bedding planes, joint planes, faults, folds, shear zones, unconformity, etc. should be studied in the field in detail and plotted on the geological map. The influence of these structural geological features on the stability of the affected slope can be evaluated with the help of stereo nets, etc.


N
Alaknanda River
Landslide Boundary
0 100 300 500
(Mtrs)
Anticline
Syncline
White Quartzite
Pink Quartzite
Metavolcanic Rocks
NH- 58
Drainage
Faults

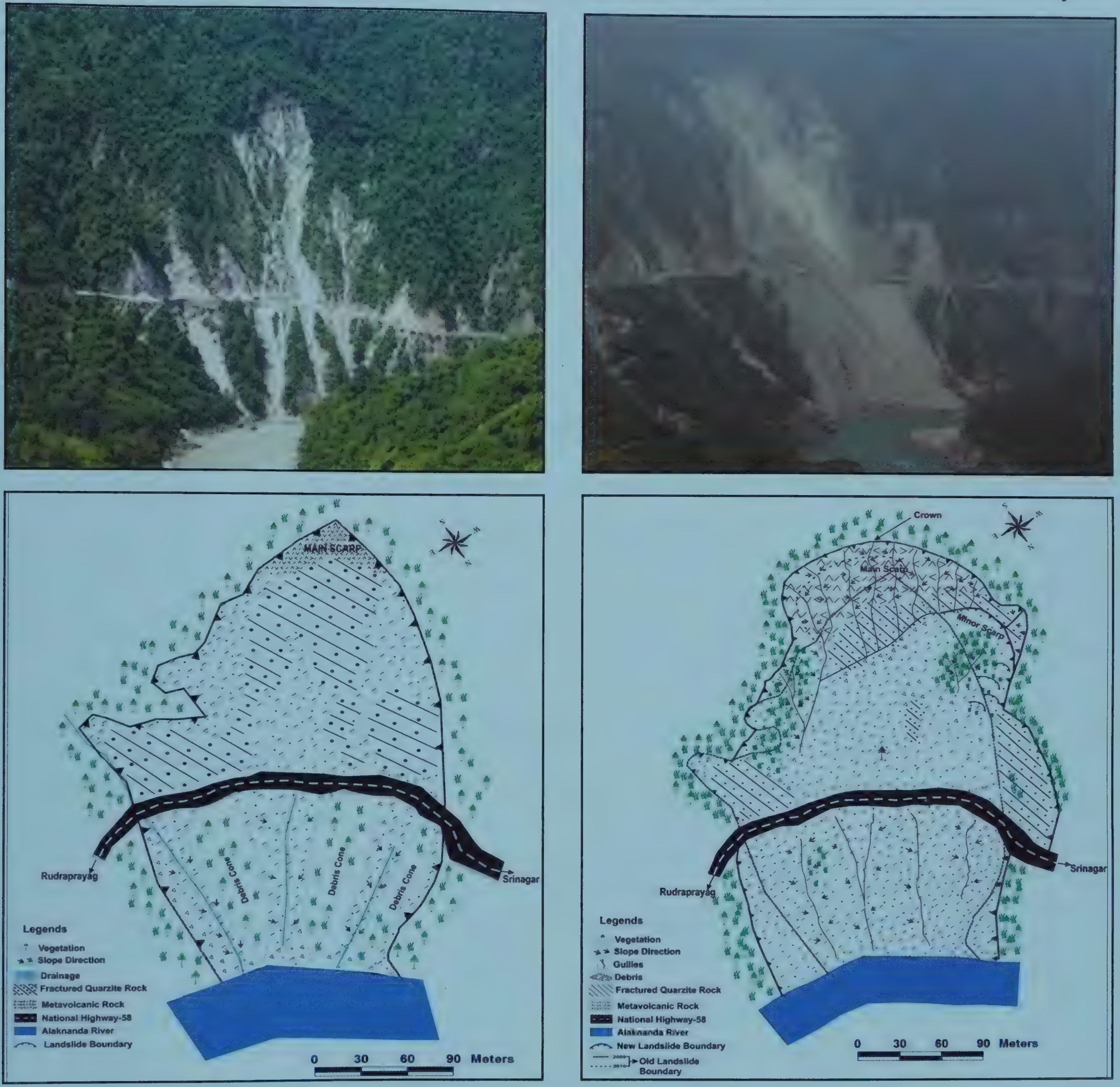
Plan


Conifer covered area
Drainage
Village Chantikhal
Subsidence
Cultivated terraces
Overburdan
Forest cover
Cracks
Crown
White quartzite
Metavolcanic rock
Debris cover
Road
Landslide area
White quartzite
Pink quartzite
White quartzite
Alaknanda river
Post August 2011
X Axis= 1cm : 25mtrs
Y Axis= 1cm: 20mtrs
1125
1105
1085
1065
1045
1025
1005
985
965
945
925
905
885
865
845
825
805
785
765
745
725
705
685
665
645
625
605
585
0
5
10
15
20
25
30
35
40
45

Section

Fig. 3.2 Geological Features of Kaliasaur Landslide

The rock types in the slide area should be identified and their qualities should be assessed. The minerals in the rocks and their alteration products should be taken into consideration. The investigation must carefully observe for the presence of any soft pockets or beds or interlayers.


MAIN SCARP
Rudraprayag
Srinagar
Debris Cone
Debris Cone
Debris Cone
Legends
Vegetation
Slope Direction
Drainage
Fractured Quarzite Rock
Metavolcanic Rock
National Highway-58
Alaknanda River
Landslide Boundary
0 30 60 90 Meters
Crown
Main Scarp
Minor Scarp
Rudraprayag
Srinagar
Legends
Vegetation
Slope Direction
Gullies
Debris
Fractured Quarzite Rock
Metavolcanic Rock
National Highway-58
Alaknanda River
New Landslide Boundary
2009
2010
Old Landslide Boundary
0 30 60 90 Meters

Geomorphic features of Kaliasaur Landslide Area (2009) Geomorphic features of Kaliasaur Landslide Area (2011)

Fig. 3.3 Geomorphological Mapping of Kaliasaur Slide Landslide (Garhwal Himalayas)

In some instances, geophysical studies may help in detecting such layers or pockets.

The study of the physical features of the surface of the earth and their relation to its geological structures is called geomorphology. On the plan of the area already prepared or on a separate map the geomorphological features should be marked. These include such features as elevated and depressed zones, break in slope, erosional and depositional zones, mass movement vectors, etc. Typical geological and geomorphological mapping of one major land-slides in Garhwal Himalayas are illustrated in **Fig. 3.2** and **Fig. 3.3** .

Seismic Refraction Test (SRT) to get the profile details in longitudinal (along road alignment) and lateral (across road alignment) directions shall be conducted.

3.3.1.3 Hydrological Investigations

(i) In most cases slope instabilities are triggered by rainfall. Hence the hydrologic dynamics that leads to changes in soil moisture and pore water pressure remains an important focal area of investigation. The following hydrological data needs to be collected for effective hydrological investigation.

  (A) Rainfall data

    a. Annual rainfall (mm)

    b. Intensity of rainfall per hour (mm)

    c. Average deviation of rainfall intensity per hour (mm)

    d. Highest deviation of rainfall intensity per hour (mm)

  (B) Catchment area above the slide area (sq.km)

  (C) Groundwater conditions in and around the slide area including as described in section

(ii) The investigation of groundwater plays an important part in any slope design program. Groundwater level depends on number of factors such as geotechnical, hydrological and hydro geological factors including permeability, intensity and duration of rainfall, rate of surface irrigation, rate of vapor-transpiration, groundwater flow etc., which need to be investigated and analyzed for reliable evaluation of slope instability. In climates with high precipitation levels, water pressure should always be included in investigations. The design water pressures should account for likely peak pressures that may develop during intense rainfall events or snow melt periods, rather than the pressure due to the average seasonal water table. Furthermore, if drainage measures are installed, the design may account for the possible degradation of these systems due to lack of maintenance. Similar to geological investigations, the extent of the ground water investigation will also depend on site conditions.

(iii) The depth and seasonal fluctuations of groundwater table also form an important component of data required for landslide Investigations. This Information may be obtained from local enquiries, observations in wells that may be present or by noting the presence of springs, etc. It is desirable to make a borehole and install a piezometer, to observe the water level over a cycle of seasons. Piezometer observation is the best way to observe groundwater regime during dry and wet periods. In such cases, it is recommended to correlate pore pressures with precipitation level, also to take into account the maximum rainfall for the time-span of the life of the structure. For better monitoring of the behavior of the site condition the installed piezometer should be maintained and monitored for minimum two monsoon seasons.

Other details such as surface and subsurface flow details (details of drains/discharge points visible, catchment details, flow details, drainage flow path etc.), channel/nallah details (geometry of the channel, gradient, channel bed properties, flow details), river flow details (water levels (high flood level, low water level, normal water level, bed level, flow velocity etc.) shall be required to be collected

The above data is used for stability analysis and formulation of corrective measures.

3.3.1.4 *Geophysical Investigations*

Geophysical testing can be used as a part of the initial site exploration to provide supplementary information to the data collected by other means (i.e., borings, test pits, geologic surveys, etc.). Geophysical testing can be used for establishing stratification of subsurface materials, the profile of the top of bedrock, the depth to groundwater, the boundaries of various types of soil deposits, the presence and depth of voids, buried pipes, and existing foundations. However, data from geophysical testing should always be correlated with information from the direct methods of exploration already discussed. There are many different types of geophysical in-situ tests such as seismic methods, electrical resistivity methods, gravity and magnetic methods etc., that can be used to obtain stratigraphic information from which engineering properties can be estimated.

Methodology for the measurement of subsurface conditions by seismic refractions and planning of the survey is given in IS 15681, Clause B.1 (Appendix D) of IS:1892 gives an outline of electrical resistivity and seismic methods used.

3.3.1.5 *Geotechnical Investigation*

(i) Geotechnical investigations shall be carried out with the objective of determining the nature and strength characteristics of the material comprising the slope. If the slope is predominantly made up of soil or a mixture of soil and rock, disturbed and undisturbed samples should be judiciously collected at a few locations covering the affected area. Disturbed samples may be made use of for determining the index properties, grain size analysis etc. Undisturbed samples may be collected from open pits or from boreholes, using appropriate type of sampling tubes. In debris covered slopes, as is very often the case in landslides affected areas of Himalayas, undisturbed samples of good quality can be collected only from open pits. Good quality undisturbed samples are a basic requirement for reliable evaluation of shear strength parameters. Drilling of boreholes / excavation of open trial pits shall be done in line with IS:1892 and IRC:123. The method of taking samples shall be as given in IS 1892 and IS 2132. The number of tests, type of tests and their location, etc. shall be provided by the designer so as to obtain a holistic view of the entire slope material characteristics and drainage pattern, so as to do a complete slope stability analysis and design of protective & rehabilitative measures. For further details regarding the scientific investigation of slopes and landslide, reference may be made of Section 5 of IRC:SP:106. If the access towards valley side slope and hillside slope is totally not possible, then Seismic Refraction Test (SRT) to get the profile details in longitudinal (along road alignment) and lateral (across road alignment) directions shall be conducted. The geophysical test such as SRT shall be carried out to establish the rock and soil profiles of varying density.

(ii) The shear strength parameters can be either obtained from laboratory tests or in-situ test when representative sample for laboratory test cannot be collected as per the prevailing site condition. Back analyses of failures are an important source of information to obtain or calibrate shear strength parameters.

It is recommended that some in-situ testings should be undertaken depending on the ground conditions. The following tests are recommended but not limited to:

(a) Standard Penetration (SPT);

(b) Cone Penetration Test (CPT);

(c) Piezocone (CPTu);

(d) Flat Dilatometre (DMT);

(e) Pressure meter (PMT);

(f) Vane Shear (VST)/direct shear

Please Note the above tests applies to various loading schemes which measures the corresponding soil response to better ascertain the material properties such as strength and/or stiffness depending on design criteria. Importantly interpretation based on the index parameters should be validated by at least one of the above field tests for the final design.

3.3.2 *Laboratory Investigations*

Laboratory testing is an integral part of geotechnical engineering. A well planned and properly executed laboratory testing program will provide soil and/or rock properties needed to perform geotechnical analyses. All tests should follow relevant standards.

3.3.2.1 Classification and Index Property Tests

i. Water Content determination

ii. Density-Void ratio determination

iii. Atterberg Limits

iv. Particle Size Distribution

v. Specific Gravity of soil solids

vi. Proctor Compaction

3.3.2.2 *Strength and Deformation Testing*

- i. Unconfined (Uniaxial) Compression
- ii. One-Dimensional Consolidation or Swell Test
- iii. Direct Shear Test
- iv. Simple Shear test
- v. Triaxial Compression (UU, CU, CD) - Triaxial Extension test

3.3.2.3 *Permeability Testing*

- i. Constant Head Testing Method – Mariotte Bottle
- ii. Falling Head Testing Method

3.3.2.4 *Laboratory Tests on Rocks*

Index Properties

- i. Slake Durability Test
- ii. Unit Weight determination
- iii. Porosity Test
- iv. Ultrasonic Wave Velocity

3.3.2.5 *Rock Strength Properties Tests*

- i. Point Load test
- ii. Uniaxial Compression Strength test
- iii. Splitting Tensile Strength Test (Brazilian)
- iv. Direct Shear test
- v. Triaxial Compression

3.4 Proforma for Collection of Data regarding Slope Instability/Landslide Occurrence and Clearance

Proforma for Landslide (Site) Data Collection

1. Location
    - i. Name of the Road:
    - ii. National Highway No.:

      or State Highway No:

      or Other roads:
    - iii. Name of the Category No.:

2. Location of the Slide:
    - i. Name of the place:
    - ii. at Km from:
    - iii. Name, if any, by which the slide is commonly referred to
3. Data to be collected regarding the slide when it is active:
    - i. Date of sliding:
    - ii. No. of times sliding has taken place in the year:
    - iii. Duration for which road was blocked by the slide No. of days/hours
    - iv. Damages to property or persons caused by the slide:
    - v. Quantity of material cleared:
    - vi. Method of clearance; Manual/or by machine and the time taken for clearing:
    - vii. Cost of clearance operation:
    - viii. Were any permanent stabilising measures executed since last sliding and If so, their efficacy:
    - ix. Is the slide preceded by rainfall or snowfall?
    - x. Is extent of area participating: In sliding.
    - xi. confined to uphill slide of road only
    - xii. confined to downhill side of road only.
    - xiii. Cover both:
    - xiv. Is the cause of slide due to man made causes such as back-cutting, etc:
    - xv. Does the slide appear to be a surficial one or a deep seated one:
4. Standard information /data to be collected about the slide:
    - **A.** **Mapping through Sketch:** Prepare a sketch of the slide area covering the slopes both uphill and downhill of the road and include the following information.
        - i. Length of slide from crown to: toe, indicating separately the length affected both above the road and below the road
        - ii. Width of the slide (parallel to the road):
        - iii. Maximum depth (Normal to the slide)

iv. General description of the slide area giving condition of the slopes, presence of erosion gullies, presence of water springs, tension cracks etc.

Note: *The sketch and the associated data should be updated after each major sliding / movement*

B. Geological Data

i. Nature of rock

Indicate whether the slide material is predominantly rock or soil, decomposed rock or disintegrated rock or a mixture of both

ii. Type of rock and formation

a. Indicate the type of rocks met with the formation

b. Indicate whether there is any inter –bedding involving especially slide susceptible formation such as shales or sandstones.

iii. Dip and strike

Indicate the dip and strikes of the rocks formation and note whether they are favorable or unfavorable for slide formation with reference to the location of the road at the stretch.

iv. Weathering

Indicate the dip and strikes of the rock formation and note weathering or other degrading process due to natural or manmade causes.

C. Geotechnical Data

a) Nature of the Soil:

i. Give the classification of soil (or soil fraction of the mantle material) and identification data according to standard soil mechanics procedure.

ii. Is there any pre-consolidated clay or shale met with?

b) Alteration of forces acting

i. Has there been any increases in the load due to construction of embankments or structures or accumulation of slide material?

ii. Has any construction work been carried out that adversely influence the stability, such as under-cutting the toe etc.?

iii. Has the slope been subjected to vibrating actions of either due to construction equipment or due to earthquakes/blasting?

c) Action of Water

i. Has any water or seepage been noticed at the joint planes or along the slide surface or in clay strata?

ii. Give a brief description of the drainage conditions prevailing in the slide area.

iii. Are there any sources of water flow nearby, such as a lake or reservoir or a river etc?

D. Causes of slide

Landslides are normally caused by a number of factors rather than a single factor. Indicate which in your opinion are the predominant causes, and give, if possible, the order of their relative predominance.

a) Geological Causes

i. Weathered rock, disintegrated and/or decomposed rock, due to various reasons like temperature changes, frost effects, other natural or manmade causes, etc.

ii. Joint planes dipping unfavourably

b) Geotechnical Causes

i. Increase in load causing sliding due to any construction or accumulation of slide material or snow.

ii. Reduction in resisting forces caused by excavation at toe.

iii. Increase in water content of clayey layers due to rainfall or seepage bad drainage, sudden draw-down, rise in water level in lake upstream.

iv. Interbeds of clay or shale or micaceous matter that are susceptible of being softened by the action of water.

E. Classification of slide:

Give the classification of the slide according to the Varnes system of classification.

F. Remedial measures:

Has the slide area been studied for evolving remedial measures?

If so, by which organization?

Give a summary of the major recommendations

Were any/all of the remedial measures Implemented? If so, detail them

What is the degree of success met with in stabilizing the slide area?

G. Recommendations:

a) Comment on future action you suggest

b) Likely behavior In future

c) Comments on any other aspects not covered above

3.5 Stability Analysis – Approach and Methods

(i) Slope instability monitoring and prediction in mountainous and natural terrain are normally challenging as well as dangerous. A detailed desktop study by integrating information such as geology, topography, elevation and slope angle are found useful in overall analysis to locate potential instability of slope. This will help us to access the applicability of spatially integrated mapping framework using combination of spatial data, geological mapping data and laboratory result testing to determine slope instability and influence factor contributing to landslide in study area.

(ii) The Slope stability analysis is generally implemented in two ways: Forward Analysis and Back Analysis.

Forward analysis is used to assess if a slope is performing safely as it was intended to, while back analysis is carried out to determine the condition of the slope that existed at the time of its failure i.e. what was the mobilized strength and the pore water pressure condition at the time of failure.

(iii) All the methods are based on the static of equilibrium. There are two ways to satisfy the static of equilibrium. The first approach considers the equilibrium of entire slope mass and solves for a single free body. The other approach divides the slope into numbers of slices where all the forces acting on each of the slices has to satisfy the equilibrium.

3.5.1 *Approach to Stability Analysis*

(i) Studies for analysis shall be holistic. The topographical mapping preferably need to be with spatial mapping (3D mapping) with advanced techniques.

(ii) The geological, geotechnical geomorphological, and hydrological studies need to be correlated with the aid of multispecialty experts for important hill road projects susceptible to landslides.

(iii) For a hill road, the hill slope, valley slope, the pavement and any water body within the slope or which is passing nearby together need to be considered for the overall stability analysis.

(iv) In a landslide area, the influential area of slope will extend multiple times (four times normally) the height of slope towards hill side and multiple times (two times normally) the height of the slope towards the valley side.

(v) Hydraulic analysis should include catchment area mapping, hydrological studies, seepage analysis, design of drainage networking.

(vi) For drainage design, parameters like rainfall data, hydrological details of a catchment area, return period and duration of rainfall are to be collected and followed as per IRC:SP:42. The Clause 9.4 of IRC:SP:42 gives the data required for the design of cross drainage works. Special requirements of drainage in hilly roads are detailed in clause no. 8.5 of IRC:SP:42. Factors affecting runoff including intensity of rainfall, duration and frequency are explained under section 6.3 of IRC SP 42. For drainage design, rainfall data, hydrological details of a catchment area, return period and duration of rainfall as per IRC:SP:42 are to be collected.

Stability analysis of soil slopes and rock slopes are covered under Chapter-3 and Chapter-4 of IRC HRB Special Report 15. Chapter-3 of IRC:75 gives stability analysis of slopes in both static and seismic condition. Stability of cohesion less slopes is covered under section 3.4 of IRC 75 and different methods of slip circle analysis (i. e. Ordinary method of slices (OMS), Taylors method, Swedish slip circle method, Bishop's method, Janbu's simplified, Spencer's method, Sarma's method, Morgenstern-Price method) for cohesive soil slopes is covered under section 3.5 of IRC:75. Stability analysis using software is covered under section 3.7 of IRC:75. Seismic slope stability aspects are covered under clause no. 3.8 of IRC:75. Table 3.1 of IRC:75 gives a summary of the recommended minimum factor of safety for stability analysis.

3.5.1.1 Back Analysis from Site Failure Mapping

Back analysis is an iterative process in which some assumed soil parameters values are considered as per engineering judgement and experience. Then the soil parameters are reduced until the most critical condition (FOS =1) is achieved which represents the state when the slope is standing just before the failure.

When a slope has failed, an analysis is usually carried out to determine the cause of failure. Given a known (or assumed) failure surface, some form of "back analysis" can be carried out in order to determine or estimate the material shear strength, pore pressure or other conditions at the time of failure. The back analyzed properties can be used to design remedial slope stability measures.

There are several methods for carrying out back analysis, few of them are as follows;

- Manual trial and error to match input data with observed behavior
- Sensitivity analysis for individual variables
- Probabilistic analysis for two correlated variables
- Advanced probabilistic methods for simultaneous analysis of multiple parameters

(a) Manual trial and error to match input data with observed behaviour

Back analysis can be performed "manually" using a trial and error procedure to determine a best fit of parameters to an existing slope failure. For example, the determination of a complex pore pressure scenario in the slope shown below, by manual back analysis using a software is described.

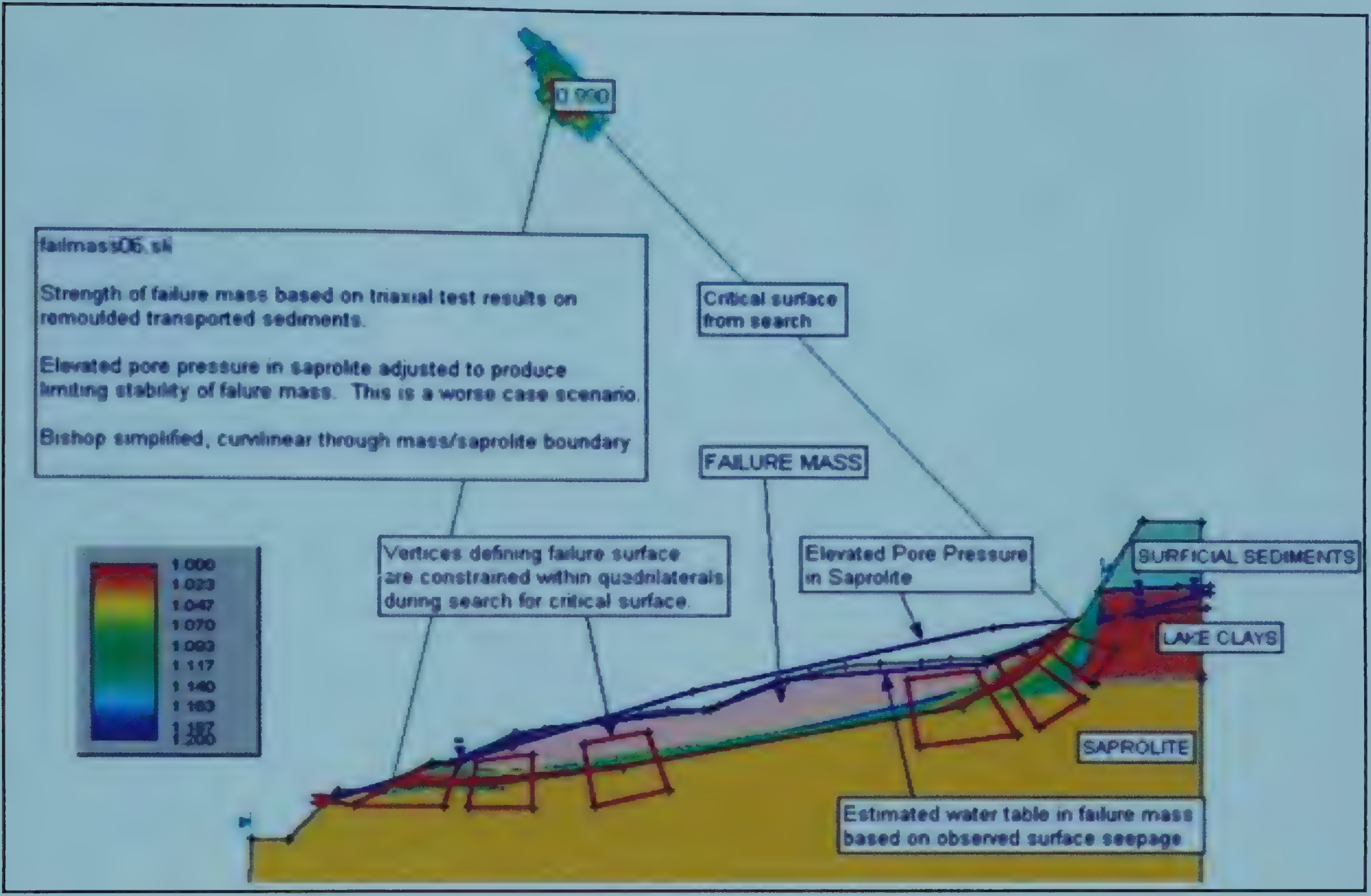

0.990
failmass06.sli
Strength of failure mass based on triaxial test results on remoulded transported sediments.
Elevated pore pressure in saprolite adjusted to produce limiting stability of failure mass. This is a worse case scenario.
Bishop simplified, curvilinear through mass/saprolite boundary
Critical surface from search
FAILURE MASS
1.000
1.023
1.047
1.070
1.093
1.117
1.140
1.163
1.187
1.200
Vertices defining failure surface are constrained within quadrilaterals during search for critical surface.
Elevated Pore Pressure in Saprolite
SURFICIAL SEDIMENTS
LAKE CLAYS
SAPROLITE
Estimated water table in failure mass based on observed surface seepage

Fig. 3.4 Typical Slide Analysis Results Snapshot – (i)

(b) Sensitivity analysis for individual variables

Sensitivity analysis allows to determine the value of a single unknown variable (e.g. cohesion or friction angle of one material) with an assumption that all the other slope parameters are known (i.e. failure surface, safety factor, strength parameters, pore pressure).

(c) Probabilistic analysis for two correlated variables

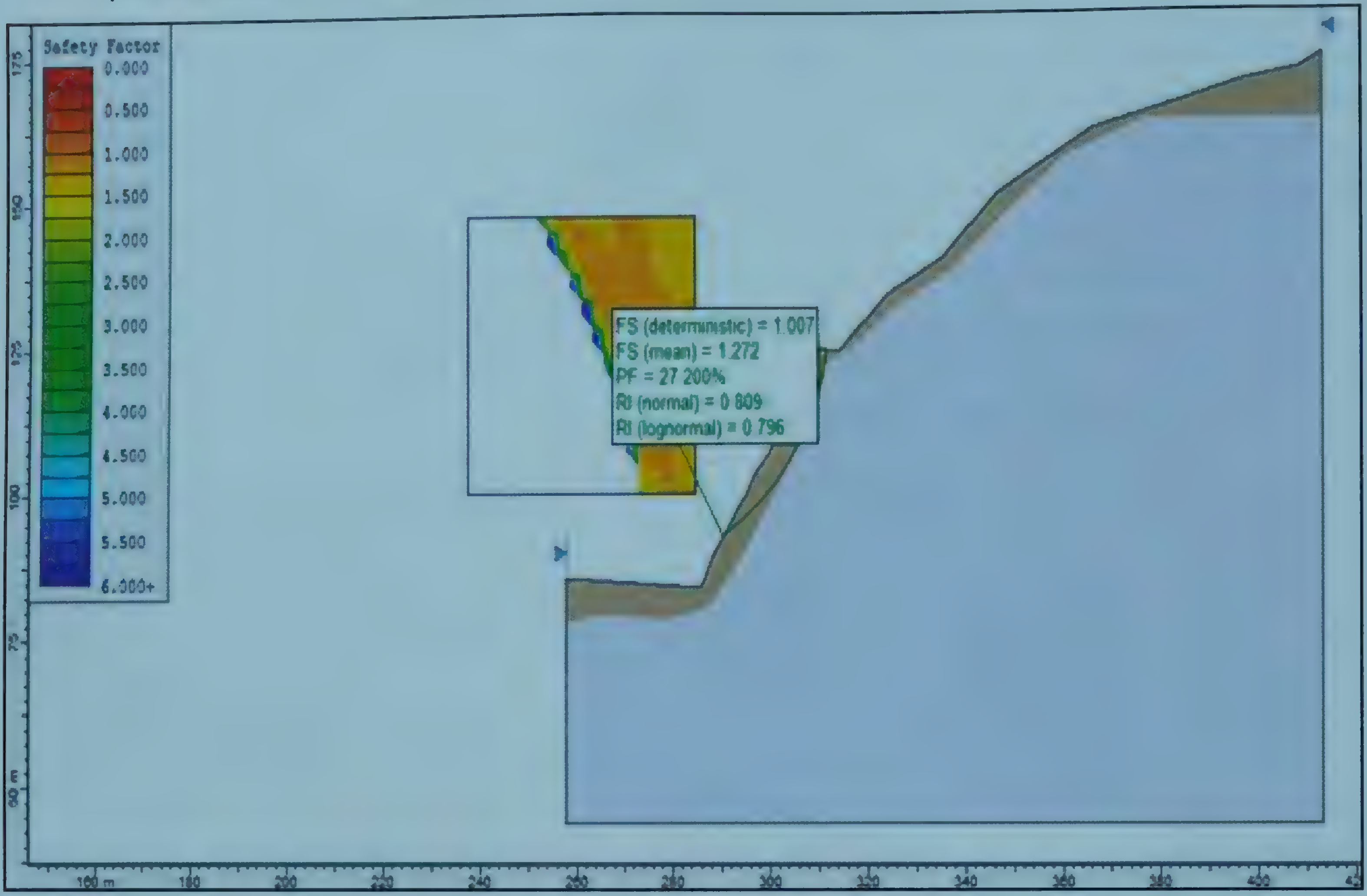
Probabilistic analysis allows to determine a relationship between cohesion and friction angle which results in a safety factor of 1 for a particular failure surface with an assumption that both cohesion and friction angle are unknown parameters.

(d) Advanced probabilistic methods for simultaneous analysis of multiple parameters

An important practical use of material strength back analysis is to determine strength parameters which are then used as input into a remedial design of a failed slope. However, real slope failures may involve progressive failure, time dependent material properties or pore pressure conditions, multiple materials, complex or anisotropic shear strength, residual strengths etc.

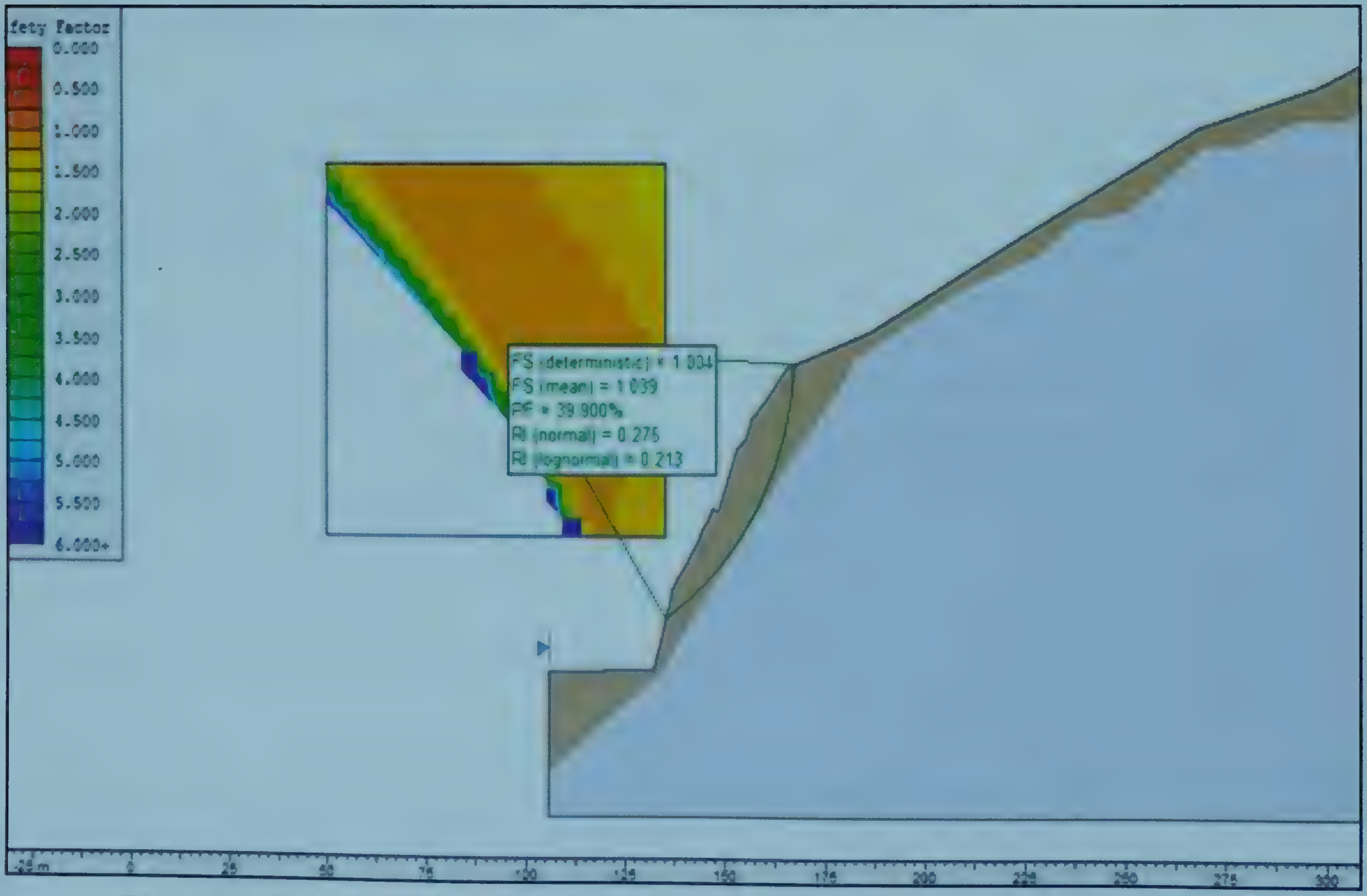
Examples of Back Analysis

Few examples are worked out by trial and error method to arrive at geotechnical parameters to be considered in the preliminary designs to arrive at a FOS =1


Safety Factor
0.000
0.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500
5.000
5.500
6.000+
175
150
125
100
75
50 m
160 m
180
200
220
240
260
280
300
320
340
360
380
400

FS (deterministic) = 1.007
FS (mean) = 1.272
PF = 27.200%
RI (normal) = 0.809
RI (lognormal) = 0.796

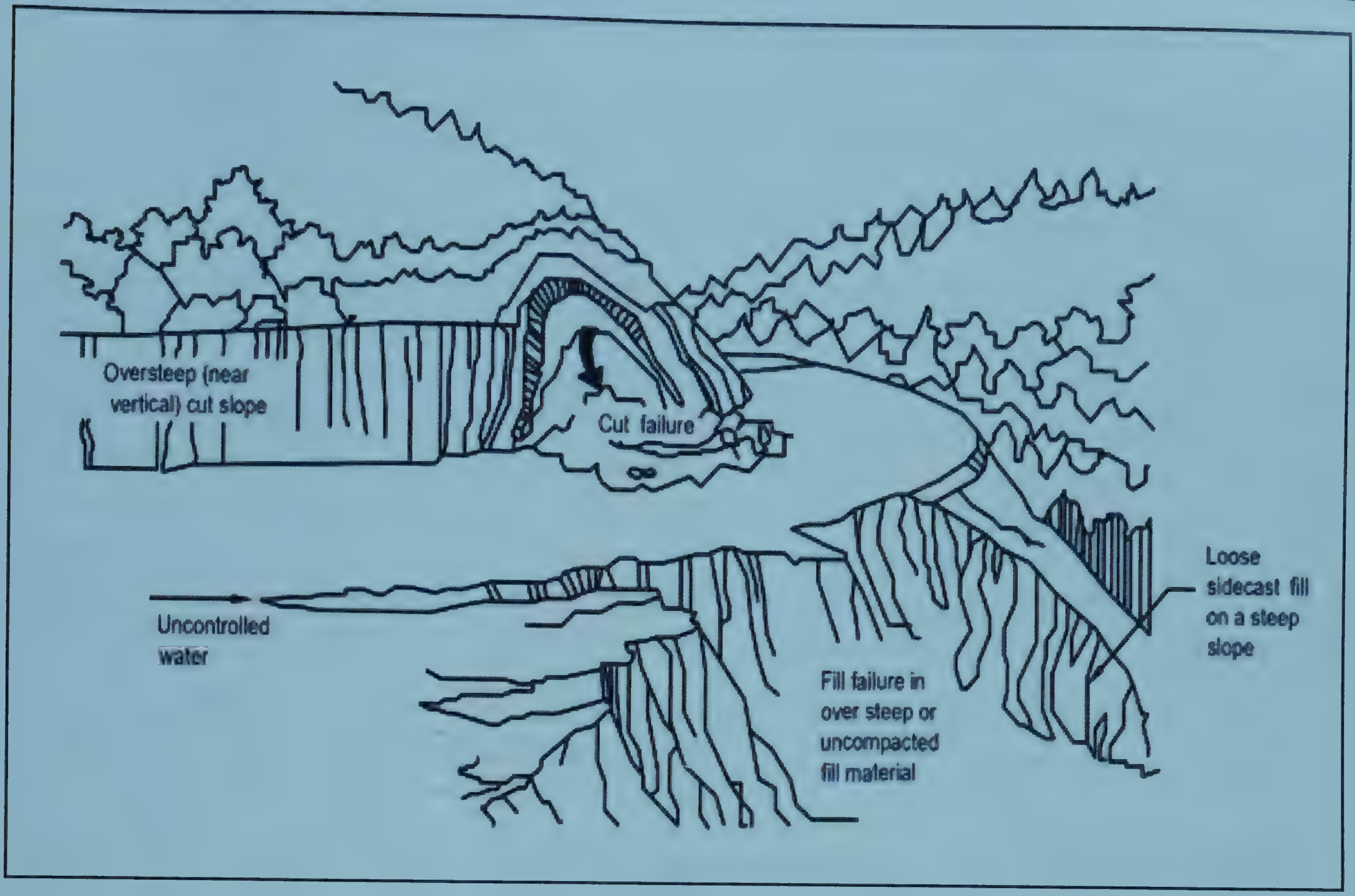
Fig. 3.5 Typical Slide Analysis Results Snapshot – (ii)


fety Factor
0.000
0.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500
5.000
5.500
6.000+
-25 m
0
25
50
75
100
125
150
175
200
225
250
275
300

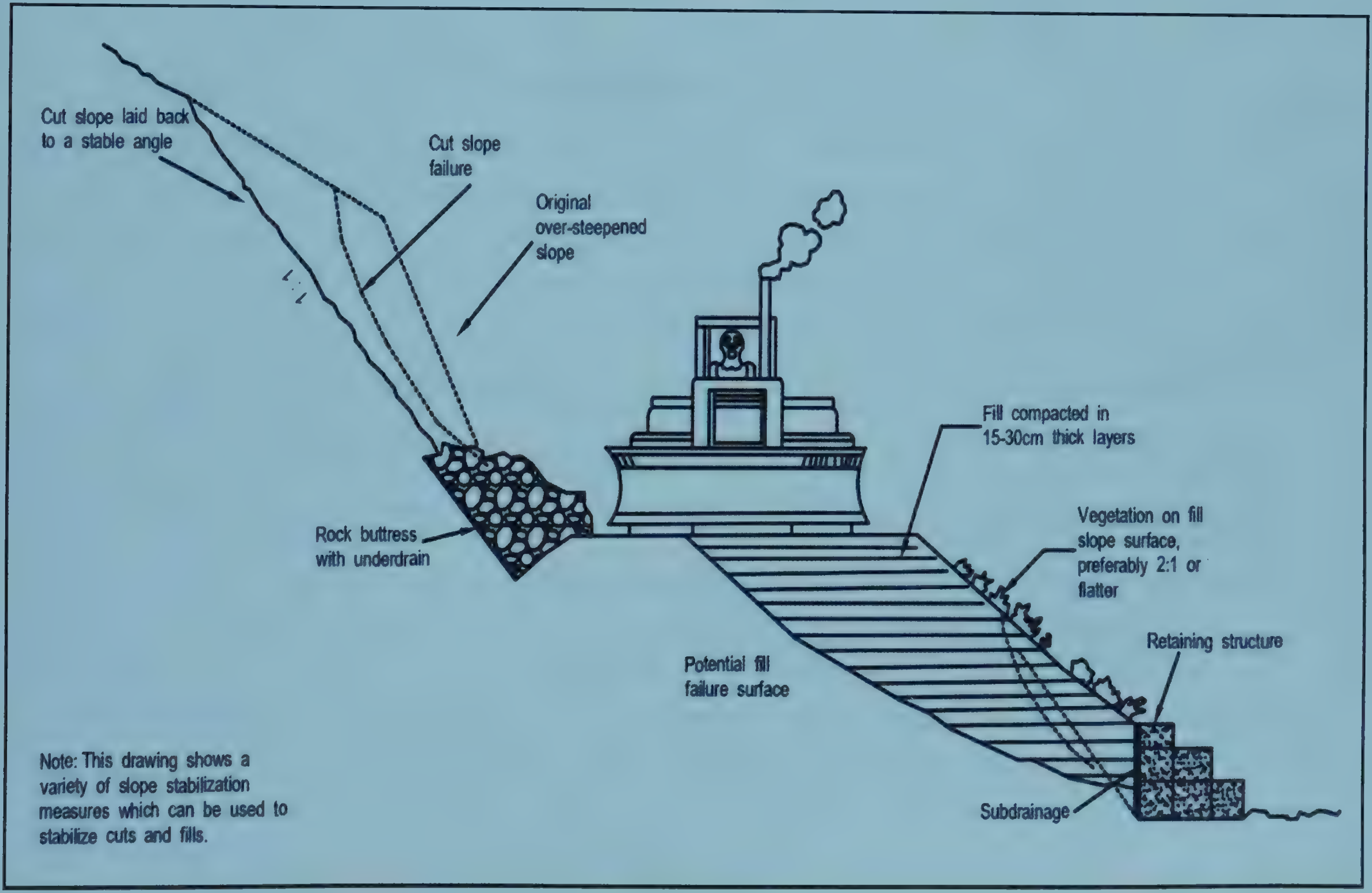
FS (deterministic) = 1.004
FS (mean) = 1.039
PF = 39.900%
RI (normal) = 0.275
RI (lognormal) = 0.213

Fig. 3.6 Typical Slide Analysis Results Snapshot – (iii)

Figs. 3.4, **3.5** and **3.6** represents a typical slide analysis result output.


Oversteep (near vertical) cut slope
Cut failure
Uncontrolled water
Loose sidecast fill on a steep slope
Fill failure in over steep or uncompacted fill material

a) Problem


Cut slope laid back to a stable angle
Cut slope failure
Original over-steepened slope
1:1
Rock buttress with underdrain
Fill compacted in 15-30cm thick layers
Vegetation on fill slope surface, preferably 2:1 or flatter
Potential fill failure surface
Retaining structure
Subdrainage
Note: This drawing shows a variety of slope stabilization measures which can be used to stabilize cuts and fills.

b) Solution

Fig. 3.7 A Typical Problem (a) and Solution (b) Where Hill Side, Valley Side and Road Stabilization together are involved

3.5.2 *Methods of Stability Analysis*

The slope stability can be analysed by circular/non-circular analysis or by deformation (stress) analysis.

3.5.2.1 Stability Analysis of Predominantly Soil Slopes

Slopes often fall by rotation as the mass slides along a curved surface. The geometry of the failure surface is predicted on many factors such as the presence of weak layers or seams, strength properties of slope forming materials, the height and inclination of slope etc. The first sign of an imminent failure of slope is usually an outward or upward bulging near the toe and development of cracks near the crest of the slope, the failure plane being approximately are of a circle. Though in actual practice the failure plane may be a complex surface i.e. Non-circular. Analysis can be undertaken for both circular and non-circular failures quite simply using any modern slope stability analysis program. It is vital to check both type of failures and design for the critical case. Reference can be made to Chapter 3 of IRC:75 for further details.

Typical sketch of slope failure, slip circle, vertical slices etc. are illustrated in **Fig. 3.8**

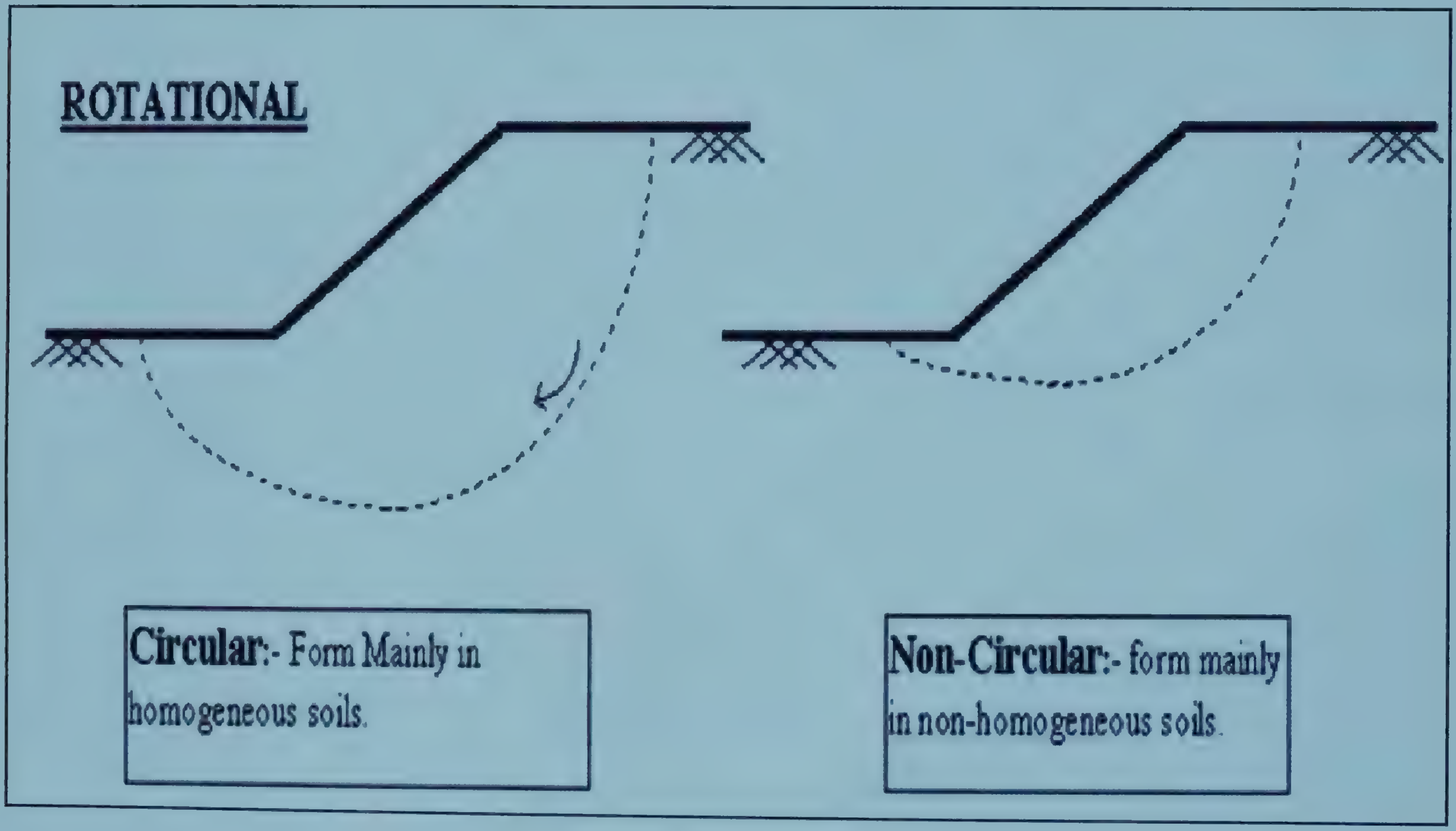

ROTATIONAL
Circular:- Form Mainly in homogeneous soils.
Non-Circular:- form mainly in non-homogeneous soils.

Fig. 3.8 Failure Types

3.5.2.2 Limit Equilibrium Methods for Stability Analysis

In all limit equilibrium methods of analysis shearing forces tending to disturb the equilibrium are quantitatively evaluated and compared with the available shear strength. This process enables the calculation of a Factor of Safety (FoS). At the out-set, continuous failure surfaces that are kinematically acceptable are assumed and calculations are made for several such surfaces. The slip surface for which the FoS is minimum is called the critical slip surface. The most common and accepted method of calculating FoS assuming circular failure surfaces is Bishop's method. For details refer to Chapter 3 of IRC:75, as stated. For Non-circular failure surfaces Morgenstern and Price or Spencers methods can be used. The **Table 3.2** provides a guide to suitable methods to use for the shape of slip surface.

Table 3.2 Different Methods of Slope Circle Analysis

Method	Force Equilibrium	Moment Equilibrium	Shape of slip surface
Ordinary method of slices (Fellenius, 1927)	Does not satisfy horizontal or vertical forces equilibrium	Yes.	Circular
Bishops Modified (Bishop, 1955)	Satisfy vertical force but not horizontal force equilibrium	Yes.	Circular only. Non circular may have numerical problems.
Janbu's simplified method (Janbu 1956)	Yes	No	Any shape. More frequent numerical problems than other methods
Morgenstern and Price (Morgenstern and Price, 1965)	Yes. Permits side forces to be varied	Yes.	Any shape.
Spencer's Method (Spencer, 1967)	Yes. Side forces are assumed to be parallel	Yes.	Any shape.

3.5.2.3 *Stability Analysis for Predominantly Rock Slopes*

Where the hill slide formation is made up of jointed rock mass, failures are governed by the relative orientation of the discontinuities within the rock mass with respect to slope of the hill face. Different types of spherical projections can be used to determine which mechanism of failure of the rock masses are kinematically possible. The results of such analysis form the basis for choosing appropriate method of analysis for evaluating the factor of safety against sliding.

Use of stereographic projections to identify failure modes

Depending upon the factors mentioned above the rock mass can have any of the failure modes such as (a) Planar failure (b) Wedge failure (c) Toppling failure and (d) Circular failure.

The mode of failure can be determined by stereographic projection based on the relationship between geological discontinuity and slope (direction and inclination). Stereographic projection is a technique used for graphical representation of rock discontinuities, given by two angles (a) the dip, which is the maximum inclination of discontinuity to the horizontal (Ψ) (b) dip direction, the direction of the horizontal trace of the line of dip measured clockwise from north (α) (**Fig 3.9**).

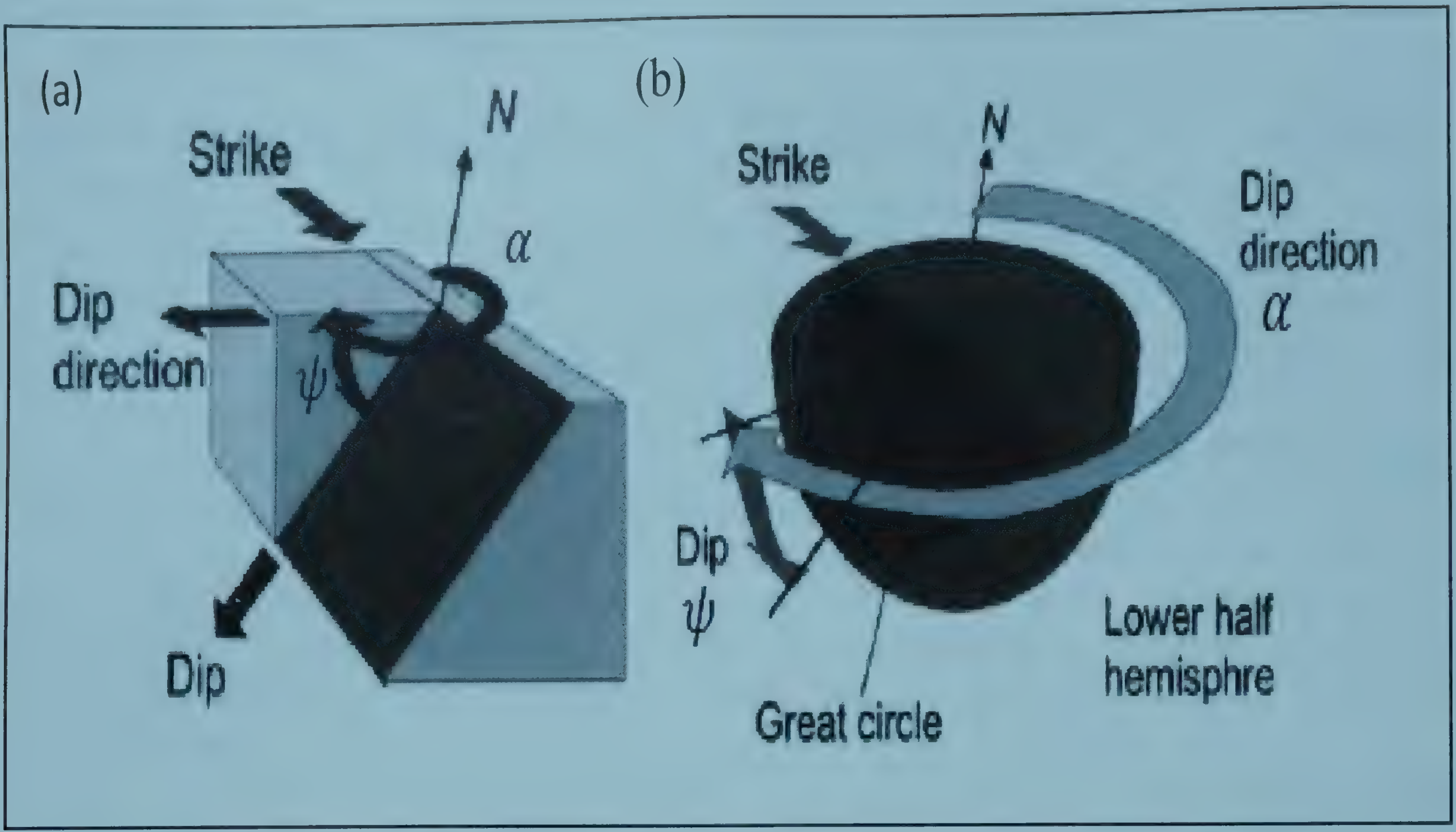

(a)
Strike
N
α
Dip direction
ψ
Dip
(b)
Strike
N
Dip direction
α
Dip
ψ
Lower half hemisphre
Great circle

Fig. 3.9 Terminology Defining Discontinuity Orientation (Dip and Dip Direction)

a) Planar failure

It is governed by a main discontinuity dipping in the direction of the slope. The favorable conditions to occur plane failure are (a) The plane on which sliding occurs must strike parallel or nearly parallel (within approximately ±20˚) to the slope face, (b) The dip of the sliding plane must be less than the dip of the slope face (c) The dip of the sliding plane must be greater than the angle of friction of the surface (d) Upper end of the sliding surface either intercepts the upper slope or terminates in a tension crack.

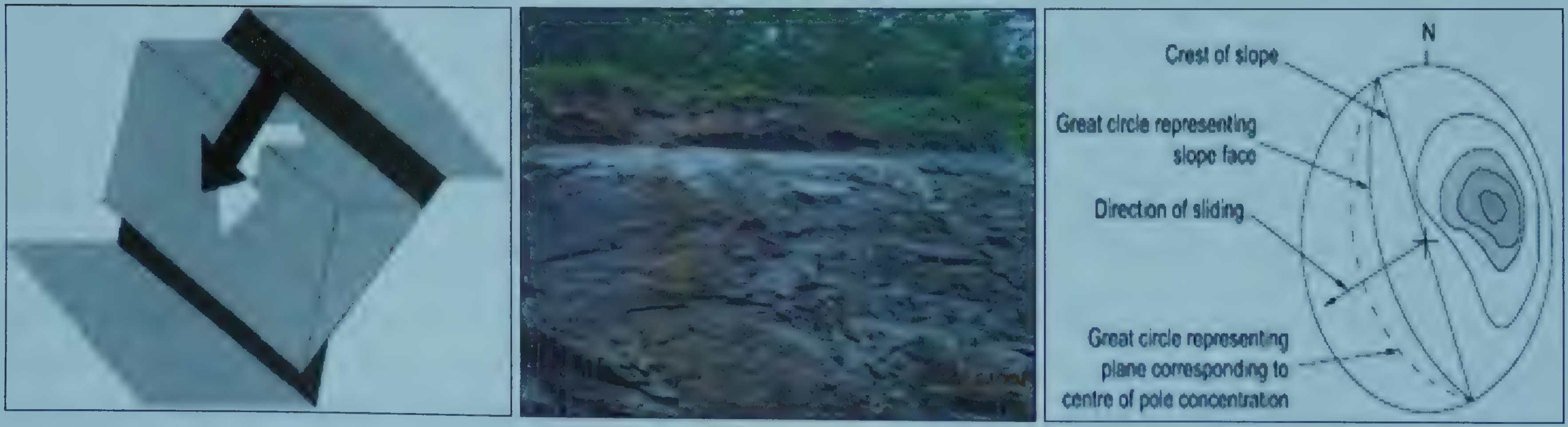

Crest of slope
N
Great circle representing slope face
Direction of sliding
Great circle representing plane corresponding to centre of pole concentration

Fig. 3.10 Planar Failure (A) Typical Sketch (B) Photograph (C) Stereographic Projection

b) Wedge failure

The mechanism is governed by two main discontinuities in which intersection lines dip towards the slope

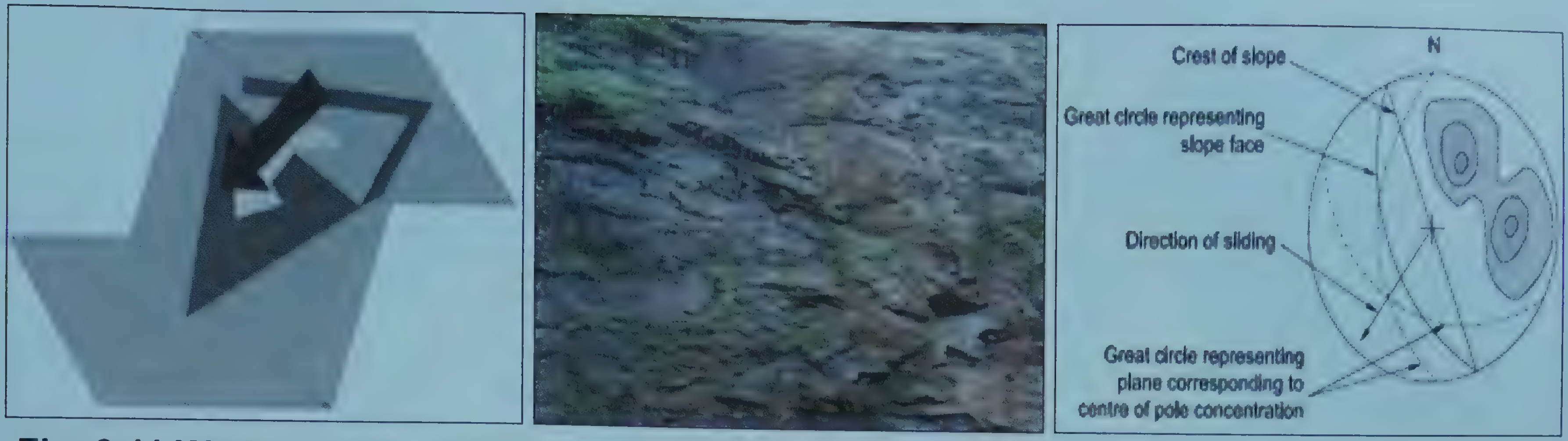

Crest of slope
N
Great circle representing slope face
Direction of sliding
Great circle representing plane corresponding to centre of pole concentration

Fig. 3.11 Wedge Failure (A) Typical Sketch (B) Photograph (C) Stereographic Projection

c) Toppling failure

Toppling of columns separated from the rock mass by steeply dipping structural features which are parallel or nearly parallel to the slope face

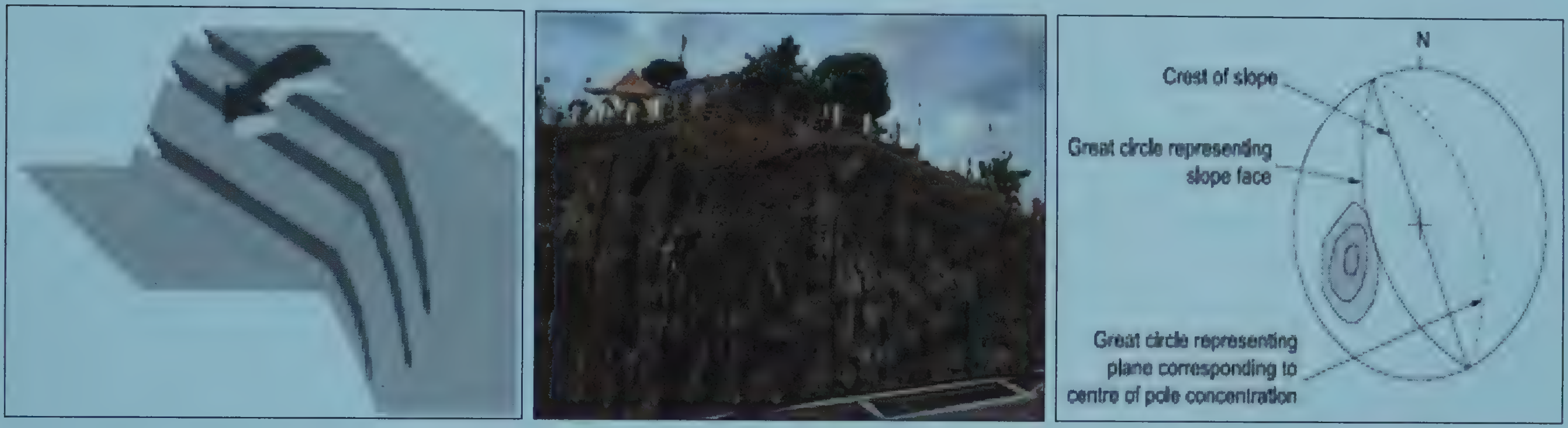

N
Crest of slope
Great circle representing slope face
Great circle representing plane corresponding to centre of pole concentration

Fig. 3.12 Toppling Failure (A) Typical Sketch (B) Photograph (C) Stereographic Projection

d) Circular failure

In case of a closely fractured or highly weathered rock, a strongly defined structural pattern no longer exists, and the slide surface is free to find the line of least resistance through the slope. In such materials, failure occurs along a surface that approaches a circular shape. The conditions under which circular failure will occur arise when the individual particles in a soil or rock mass are very small compared with the size of the slope. Hence, broken rock in a fill will tend to behave as a "soil" and fail in a circular mode when the slope dimensions are substantially greater than the dimensions of the rock fragments.

The stability analysis of circular failure is carried out using the limit equilibrium procedure which involves the comparison of the available shear strength along the sliding surface with the force required to maintain the slope in equilibrium.

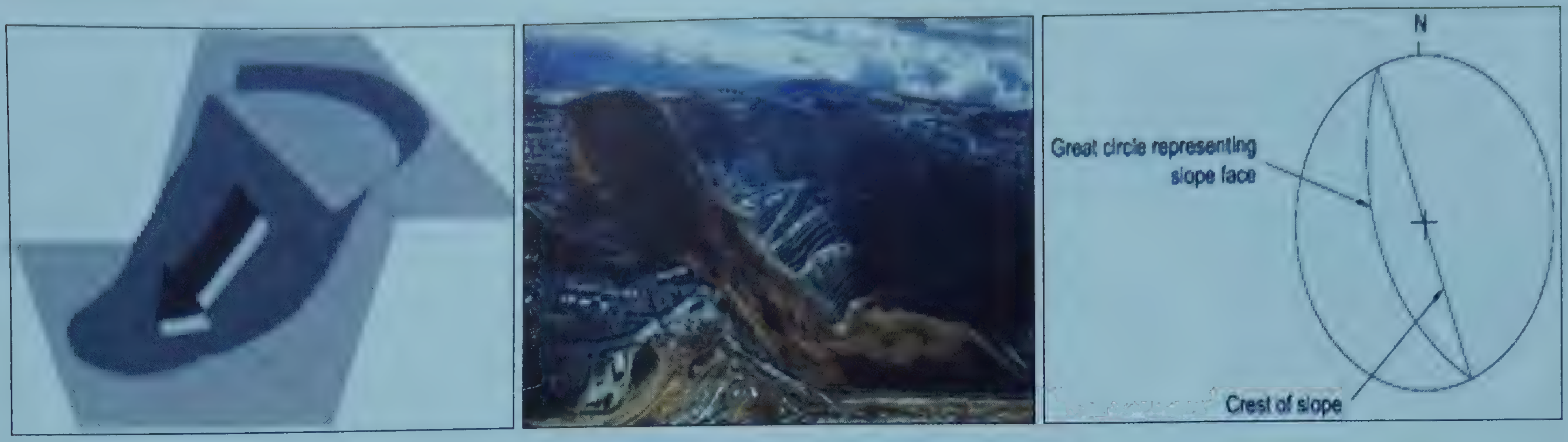


Fig. 3.13 Circular Failure (A) Typical Sketch (B) Photograph (C) Stereographic Projection

e) Rock fall

Rock fall consists of fall of loose blocks or slabs due to slipping, rolling or toppling on the slope. There are cases in which large number of loose blocks are susceptible to sliding making it extremely difficult to fix them all. In this case, the most feasible stabilization method is to reduce risk by controlling rockfall and the use of barriers. These methods will be discussed in detail in another **Chapter-4.** In such cases, prediction of the rockfall path is important.

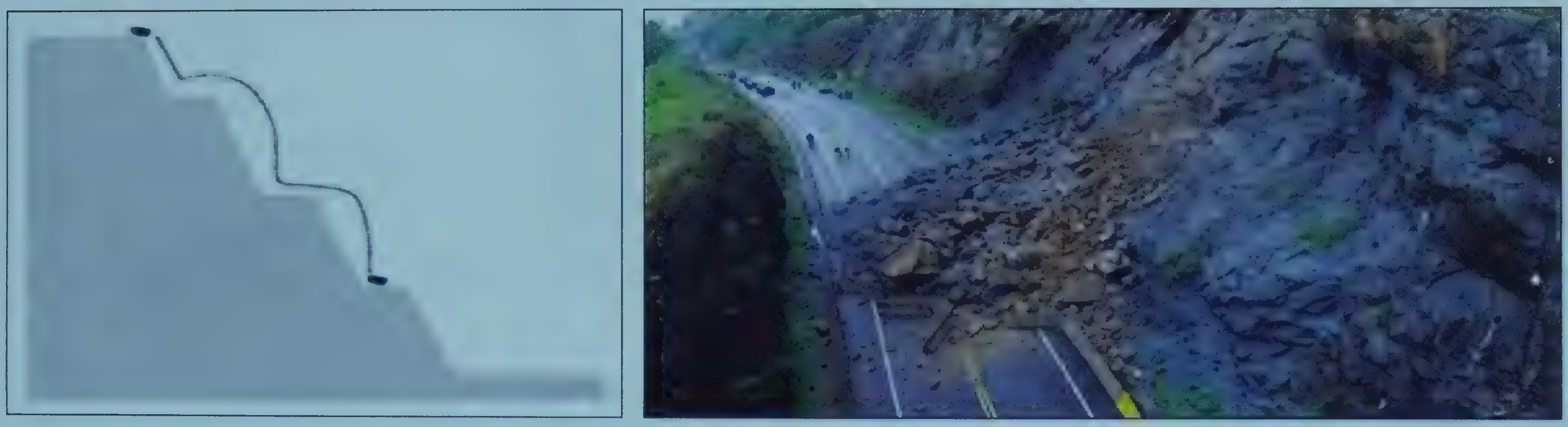


Fig. 3.14 Rock Fall/Slide (A) Typical Sketch Showing Rolling/Toppling of Rock on Slope (B) Typical Picture Showing Slide of a Rock Mass

Table 3.1 Critical Parameters Required for the Analysis for Various Failure Modes in Rock Slope

Failure Mode	Method of Analysis	Critical Parameters required for Analysis of Rock Slope
Planar failure	2D limit equilibrium analysis	Slope height, slope angle Rock unit weight Slope angle of failure plane Dip and dip direction of tension crack (if any) Shear strength parameters of the failure plane Ground water distribution in slope Potential earthquake loading

Wedge failure	3D wedge failure analysis, limit equilibrium method	Slope height Rock unit weight Dip and direction of the two joints, slope face, upper surface Dip and dip direction of tension crack (if any Shear strength parameters of the two joints Ground water distribution in slope Potential earthquake loading
Toppling failure	Limit equilibrium analyses of simplified block models are useful for estimating potential for toppling and sliding Discrete element models of simplified slope geometry can be used for exploring toppling failure	Slope height, angle Rock unit weight Spacing of toppling joint Dip of toppling joints Overall base inclination Shear strength parameters of base joint and toppling joint (friction angle, cohesion, tensile strength) Groundwater distribution in slope Potential earthquake loading
Circular failure	2D limit equilibrium method with automatic search of the critical slip surface	Slope height, slope angle Shear strength of materials along failure surface Groundwater distribution in slope Potential surcharge or earthquake
Rock fall	Calculation of trajectories of falling or bouncing rocks based upon velocity changes at each impact Monte carlo analyses of many trajectories based upon variation of slope geometry and surface properties give useful information on distribution of fallen rocks	Slope height, slope angle Presence of loose boulders Coefficients of restitution of materials forming slope Presence of structures to arrest falling and bouncing rocks

- The interactions of joints and bedding planes with reference to a given plane are normally evaluated by resorting to spherical projections and by use of stereonets. With the help of such stereonets, it will be possible to identify if sliding is likely to occur on a single plane or along two planes or over a set of stepped joints etc. Reference may be made to Goodman (1980) “Introduction to

Rock Mechanics" for details concerning the application of stereonet projection methods for evaluating stability of rock slopes.

- In certain situations, sliding in a slope made up of rock mass can also be analysed by slip circle analysis, discussed in the previous section. Some of such conditions are:
    a) The rock mas on hill face is highly fractured and has randomly oriented joints.
    b) The rock mass has low strength and its strength characteristics approach that of soil.
    c) Faults or pre- shear planes or other discontinuities may exist, which may include failure along non-linear slope surface.
- Notwithstanding the above, the geological and geomorphological study of the rocky area and devising corrective measures would normally be adequate for meeting most requirements of rocky slopes on hill roads.

3.6 Recommendation

The contents discussed in this chapter play a very important role to arrive at a full proof slope stability solution. Landslides are dangerous, disruptive to the development and costly to repair. Acceptable values for probability of failure can be adopted based on the consequences of failure. Hence they should be accurately assessed.

4. SLOPE STABILITY, LANDSLIDE & ROCKFALL MITIGATION MEASURES

4.1 General

4.1.1 A hill road is formed either by complete cutting into the hill side or part cutting and part filling. Typical sections are given in **Fig. 4.1**. Stability of slopes natural and man-made, is important for a hill road. Disturbance to slope can occur due to erosion caused by rain fall and run-off and consequent slides. Slope stabilization measures, effective erosion control measures and good drainage system protect slopes and prevent or mitigate slides. The subject of slope stability and erosion control, therefore, become very vital for control and prevention or mitigation of landslides/slips.

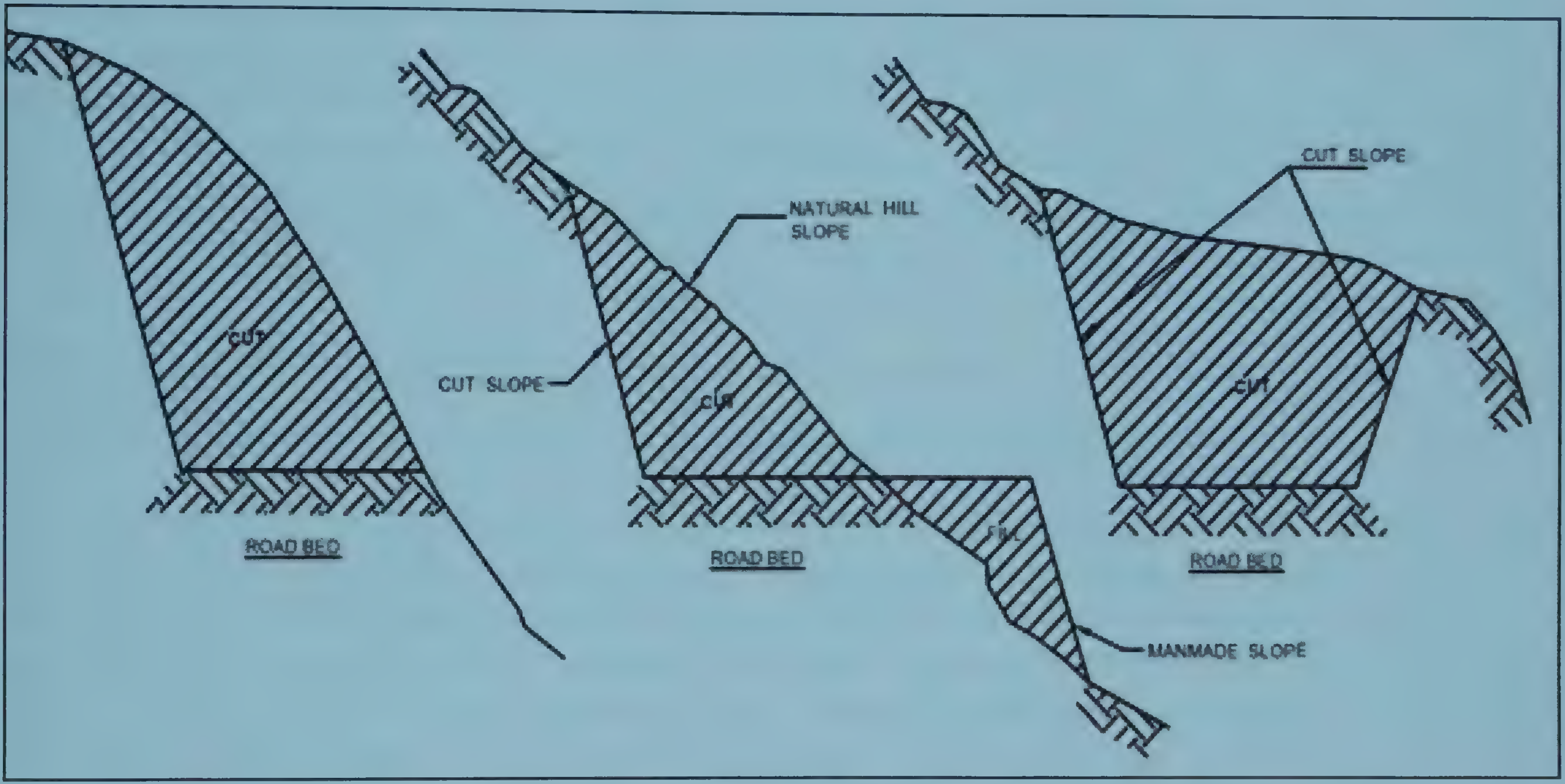


Fig. 4.1 Slopes in Hill Roads - Natural, Man-Made, Cut and Fill Slopes

4.1.2 Landslide, debris flow, rockfall, avalanche, river toe cutting, and erosion is a major hazard faced on hill roads. Study of stability of natural slopes, control of landslides / rockfall and design of surface / sub-surface drainage system thus forms an Integral part of hill road design and construction.

4.1.3 A landslide may be defined as the failure of a slope mainly under the action of its own weight in which the displacement has both vertical and horizontal components of considerable magnitude. Landslide denotes downward and outward movement of slope-forming materials composed of natural rock, soil, artificial fill or a combination of these materials. The moving mass follows any one of three principal types of movements viz. falling, sliding, flowing or their combinations. The rate of movement may vary from slow to rapid.

4.1.4 No slope on cutting as well as filling on hill/mountainous roads shall be left unprotected and each slope portion of the cutting and filling of the hill/mountainous road shall be protected from failures in accordance with stability consideration as detailed in **Chapter-3**. The cut and fill side portion of slope on hills and dumping yards shall be protected from failure by constructing adequately designed engineered structures like retaining walls, toe walls, breast walls, erosion control measures, reinforced soil structures, nailing/anchoring/bolting, rockfall mitigation measures, river training structures or any other appropriate technology with proper drainage network.

4.1.5 The slopes of embankment in valleys/fill shall be protected from erosion by adopting different methods of slope protection using vegetation such as simple vegetative turfing, transplantation of ready-made turfs or grass, application of mulch, vertiver grass, use of coir and jute mats, use of 2D synthetic geo-grids/netting, use of three-dimensional erosion control mats, preformed polymer geo-cells or webs etc. as per IRC:56 and MoRTH 700 besides providing adequately designed slope stability structures required as per the site condition.

4.1.6 Appropriate estimation of muck generation and its disposal at designated locations shall be made. The muck shall be disposed of at designated locations and retained by providing suitably designed retaining structures with appropriate drainage arrangements of backfill so that ingresses water may not carry soil fines along with it and all retained material is prevented from mixing with the streams. The muck disposal sites shall be covered by growing local variety of vegetation over it before completion of the work. The muck dumping structures shall be designed as permanent structure.

4.2 Classification, Causes, Investigation & Stability Analysis of Slope Movement

a) Classification of Slope Movements

In order to select an appropriate corrective measures in terms of prevention or rehabilitation, it is necessary to understand the type of movement or slope failures, classification of slope movements and accordingly a scheme for landslide prevention shall be chalked out. This would require a thorough investigation of the hill slope to carry out slope stability analysis and accordingly design the appropriate measures. The aspects of investigation and stability analysis along with classification are covered in **Chapter-3** and IRC:SP:106 "Engineering Guidelines on Landslide Mitigation Measures for Indian Roads".

b) Causes of Slope Movements

Before designing the appropriate measures for prevention and rehabilitation, the causes of slope movement should be clearly defined, and the parameters required for slope stability and design of systems should be established in a clear-cut manner. This would help in selecting an appropriate type of structure and designing the same. These aspects are being adequately provided in **Chapter-3.**

c) Landslide Investigations

Investigation and study of landslides broadly comprises of field and laboratory Investigations. Both geological and geotechnical aspects, in the broad sense of the terms, need to be studied. The objective of these studies is to collect data for the evaluation of the stability of the slope, determine the conditions under which failure may occur and base the remedial measures on a rational footing. For further details on investigations, reference shall be made to **Chapter-3.**

d) Stability Analysis

Stability analysis is defined as the analytical method to quantitatively evaluate the degree of stability of slope. In the detailed design stage, stability of cut/fill slope is evaluated using different stability analysis methods. Slope stability analysis is the basis of detail design and shall be carried out. For further details on stability analysis, reference shall be made to **Chapter-3**.

4.3 Protection, Prevention & Stabilization Measures

Several remedial, corrective or control methods are practiced to protect hill slopes from instability. These are briefly discussed under three broad categories.

a) Avoid or eliminate the problem itself.

b) Reduce the forces tending to cause movement i.e. the driving forces.

c) Increase the forces resisting the movement

4.3.1 *Avoid the problem*

The problem may be avoided or eliminated by one the following methods:

(A) **Change of alignment:** During reconnaissance, potential stability problems such as poor surface drainage, seepage zones on existing natural slopes, hill side creep and old landslides should be carefully noted. Early recognition of known troublesome areas help in deciding for choice of alternate alignments. It is often more practicable to avoid a potential landslide by changing the alignment of a proposed highway initially rather than resorting to elaborate remedial measures. In some places, it may be possible to choose the opposite side of valley or hill where the bedding planes of the rock dip away from the cut slope rather than dip towards the cut.

(B) **Bridging:** In some cases, when removal of steep, long and narrow unstable slope is too costly then Bridging is one of the alternatives. A land bridge or a structure founded on piles placed well below the unstable foundation materials is constructed, spanning the unstable area. A sketch illustrating this is given in **Fig. 4.2.** Care must be taken as areas may be affected by debris flow or possible rock fall activities. Therefore, it is recommended that a proper site survey be undertaken to highlight any potential problems at the design feasibility stage.

(C) **Tunneling:** An unstable alignment can also be avoided by resorting to tunneling, if the geological strata at a suitable depth are found to be stable. Due to increasing demands of safe and uninterrupted traffic movements in hill areas, these solutions have to be resorted to. An illustrative sketch is given in **Fig. 4.3.** IRC:SP:91 "Guidelines for Road Tunnels" shall be referred for further reference. Alternatively cut and cover RCC three pin pre-cast tunnel/ structural shades can also be good economical solution to avoid any major land slide zone subject to the condition that the foundation soil and valley side slope is stable (**Fig. 4.4**). Only reinforced concrete type of arch structure shall be adopted for such solutions. Precast Cut and Cover Tunnels have distinct advantages over the conventional cast-in-situ cut and cover box section. These advantages are based on the saving in material, time constraints, ease of erection, short working seasons and extreme weather condition for casting of concrete. However, the feasibility of such solution will depend on various factors like geometry, available space, foundation condition, overall stability of base and foundation toe slope etc.

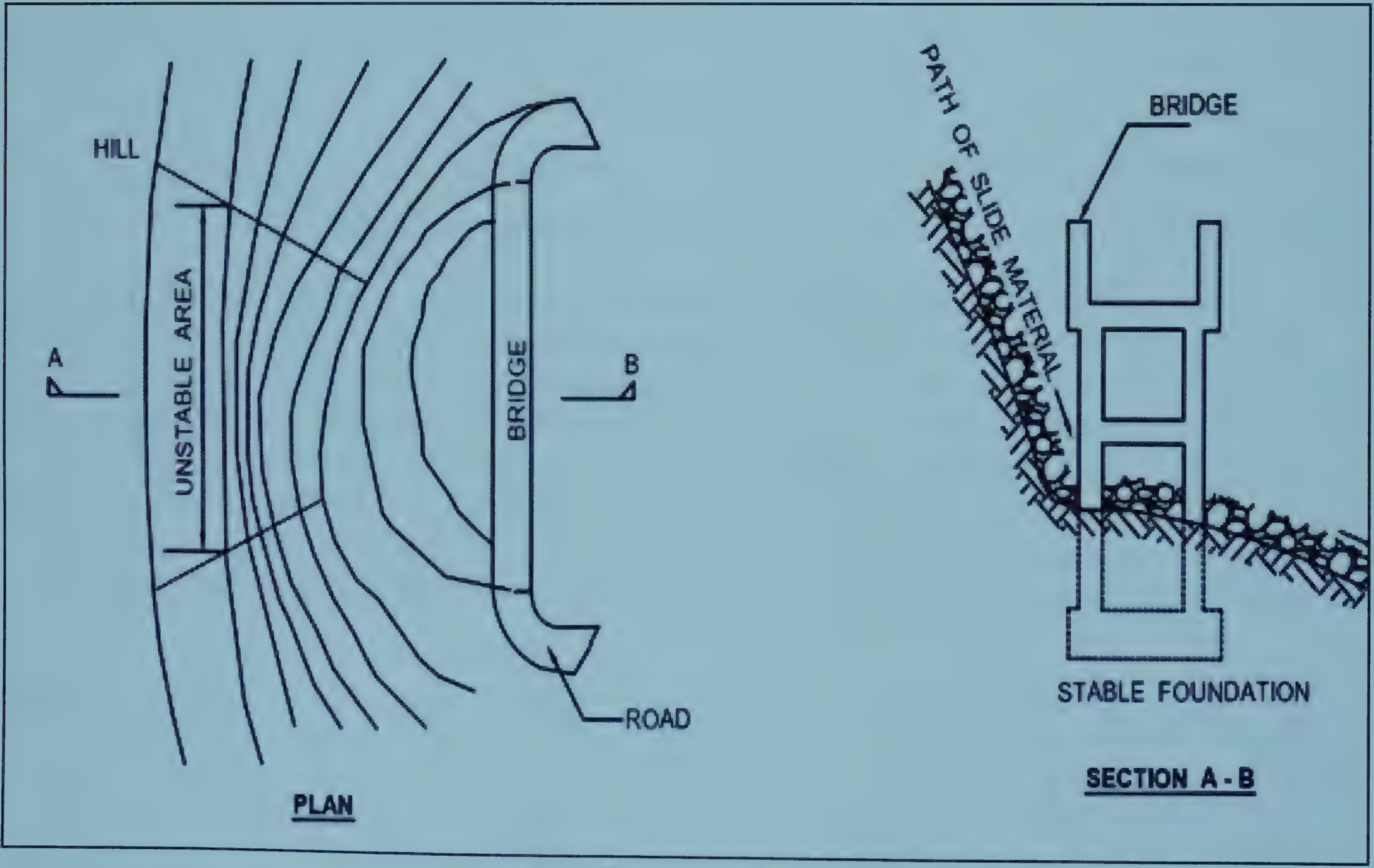


Fig. 4.2 Bridging Unstable Area

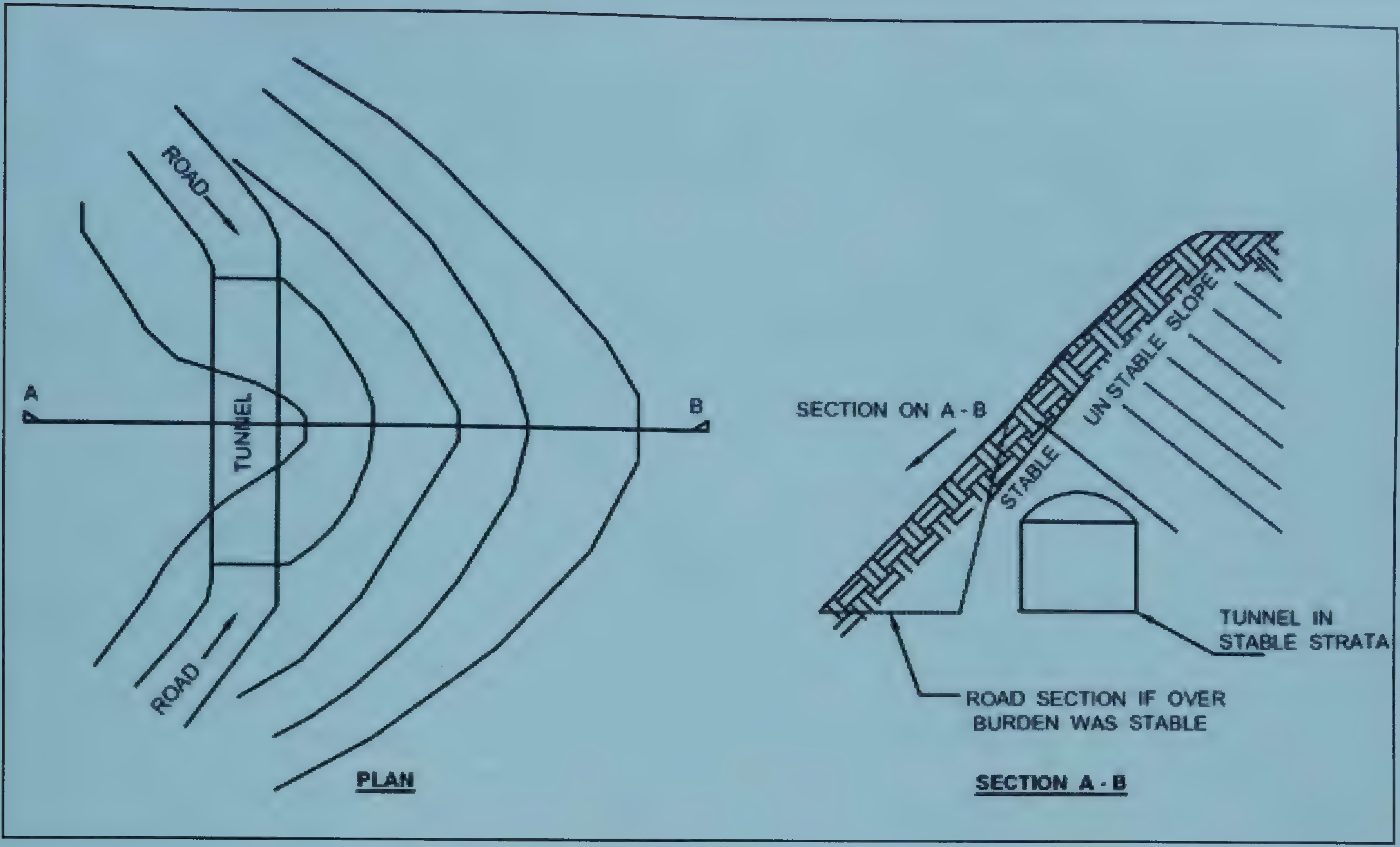

ROAD
A
B
TUNNEL
ROAD
PLAN
SECTION ON A - B
UN STABLE SLOPE
STABLE
TUNNEL IN STABLE STRATA
ROAD SECTION IF OVER BURDEN WAS STABLE
SECTION A - B

Fig. 4.3 Tunnel to Avoid Unstable Slope

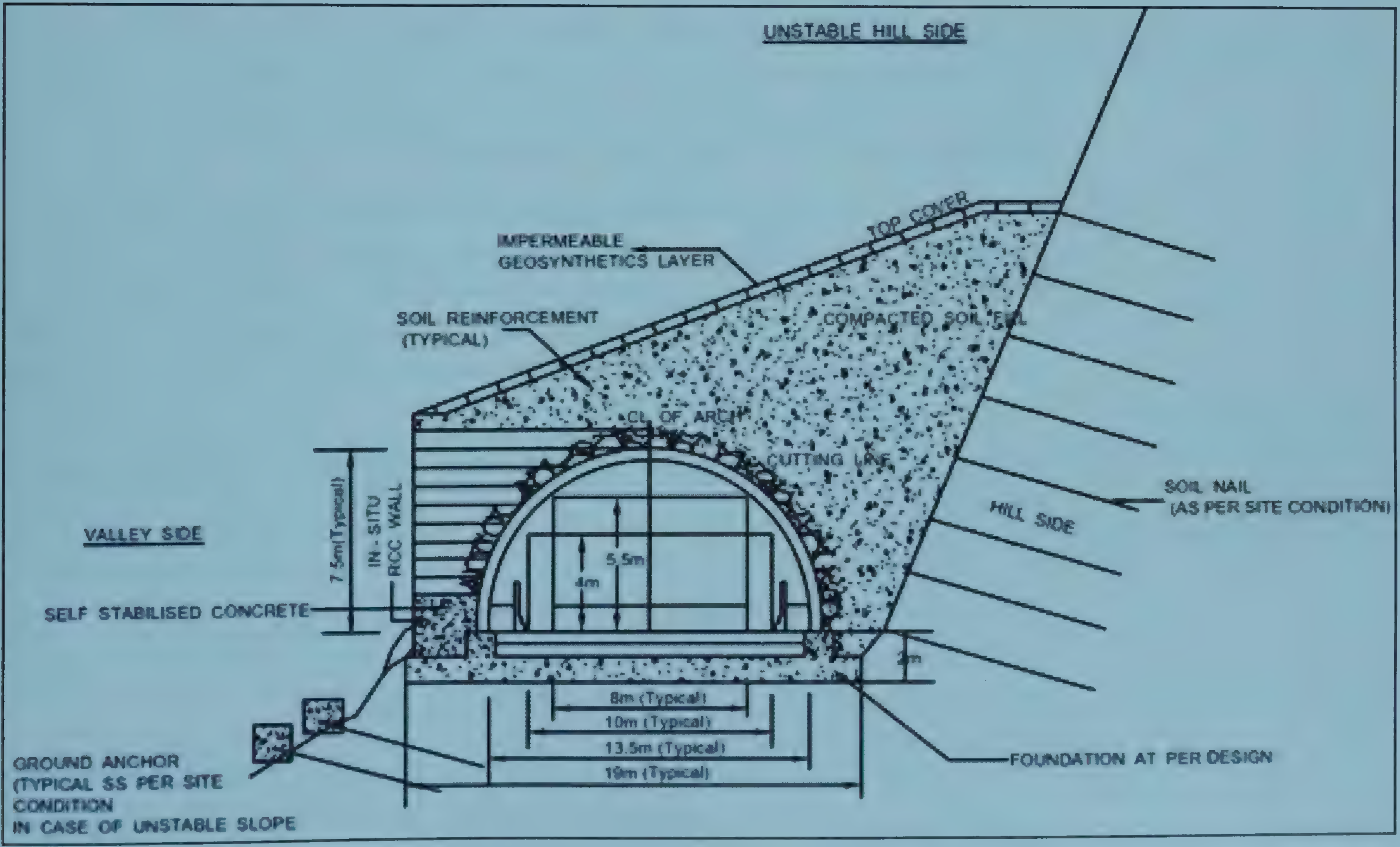

UNSTABLE HILL SIDE
TOP COVER
IMPERMEABLE GEOSYNTHETICS LAYER
SOIL REINFORCEMENT (TYPICAL)
COMPACTED SOIL FILL
CL OF ARCH
CUTTING LINE
SOIL NAIL (AS PER SITE CONDITION)
HILL SIDE
VALLEY SIDE
7.5m(Typical)
IN - SITU RCC WALL
5.5m
4m
SELF STABILISED CONCRETE
2m
8m (Typical)
10m (Typical)
13.5m (Typical)
19m (Typical)
FOUNDATION AT PER DESIGN
GROUND ANCHOR (TYPICAL SS PER SITE CONDITION IN CASE OF UNSTABLE SLOPE

Fig. 4.4 Typical Section of RCC Pre-Cast Cut and Cover Arch to Avoid Unstable Slope(dimensions are indicative. To be decided as per design)

4.3.2 *Reduce the Driving Forces*

The driving forces comprise of the component weight of the soil, superimposed loads and water (surface runoff and pore water pressure). The simplest approach to reduce such forces is to reduce the mass involved. There are mainly three methods by which the driving forces can be reduced as described hereafter.

(A) **Change the line or grade**: Line or grade changes are generally done to reduce the driving forces. Shifting the highway alignment away from the toe of the slide area eliminates the need to provide toe support. Where necessary, a suitable protection/retention measures may be placed to support the sliding mass in the form of a retaining type structure.

(B) **Surface Drainage:**

(i) Drainage not only reduces the weight of the mass tending to slide but also increases the strength of the slope-forming material. A high degree of surface erosion and development of excess pore pressure within the slope, due to the absence of proper drainage facility are the two principal causes of slope instability. It is, therefore, essential that improvement of the drainage facilities in the area be given high priority.

(ii) Mere provision of contour drains, culverts and drainage chutes does not help if it is not ensured that the catchment would effectively feed them, and that the drainage system is firmly founded. A number of rows of inter-connecting lined catch-water drains should be constructed on the slope to collect the surface run off which should in turn be brought to culverts at a lower level to be led through chutes to natural watercourses. Lined roadside drains should also be built. The different type of drains and drainage works are described in **Chapter 2.**

(iii) To prevent intrusion of direct rainfall in the loose mantle of earth along the slopes, a vegetative cover should be provided. Sealing· of tension cracks on the surface of the slope in any type of landslide will prove beneficial since it prevents the ingress of surface water into the slide mass. (Methods of sealing of tension cracks and provision of vegetative cover are dealt separately later).

(iv) Surface drainage mitigation should also include the following where required:

(a) Reshaping of the slopes

(b) Construction of paved ditches

(c) Installation of drainpipes and

(d) Paving or bituminous treatment of slopes.

(v) The surface drains must be provided with impervious paving and have a uniform gradient to prevent deposition of material silt in the drain (**Fig. 4.5**). Surface drainage may also be used in conjunction with other types of treatment such as erosion control measures, river training measures, rock fall mitigation measures, etc.

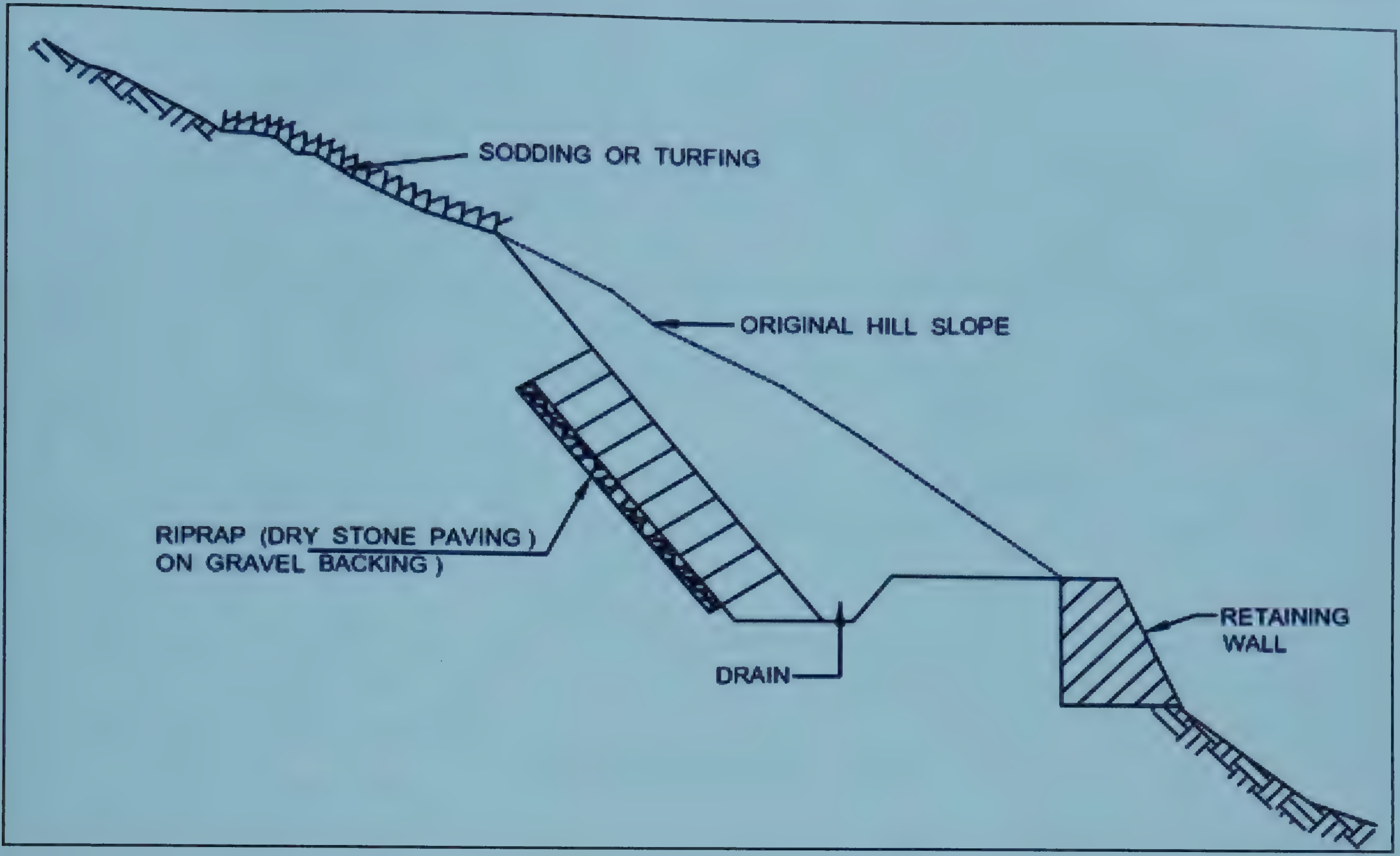


Fig. 4.5 Sodding and Riprap

(C) **Sub-surface Drainage:** Removal of sub-surface water tends to produce a more stable condition in several ways such as:

i) Seepage forces are reduced

ii) Shear strength is increased

iii) There is reduction in excess hydrostatic pressure

iv) Driving forces are reduced

The removal of water within a slope by sub-surface drainage is usually costly and difficult. Methods generally used to accomplish sub-surface drainage are the installation of horizontal drains deep trench drains, vertical drainage wells and drainage tunnels. Sub-surface drainage has also been dealt in **Chapter- 2**. However, drains related to slope stability not covered earlier, are described below:

(C1) Horizontal Drain

Horizontal drains may be used in slopes where steady seepage of water is encountered. They provide channels for drainage of sub-surface water either from the sliding mass or from its source in the adjacent area. It has been observed that installation of such horizontal drains is very effective in lowering the ground water level and thus stabilizing the slopes. A typical sketch and arrangement of horizontal drain is given in **Fig. 4.6.**

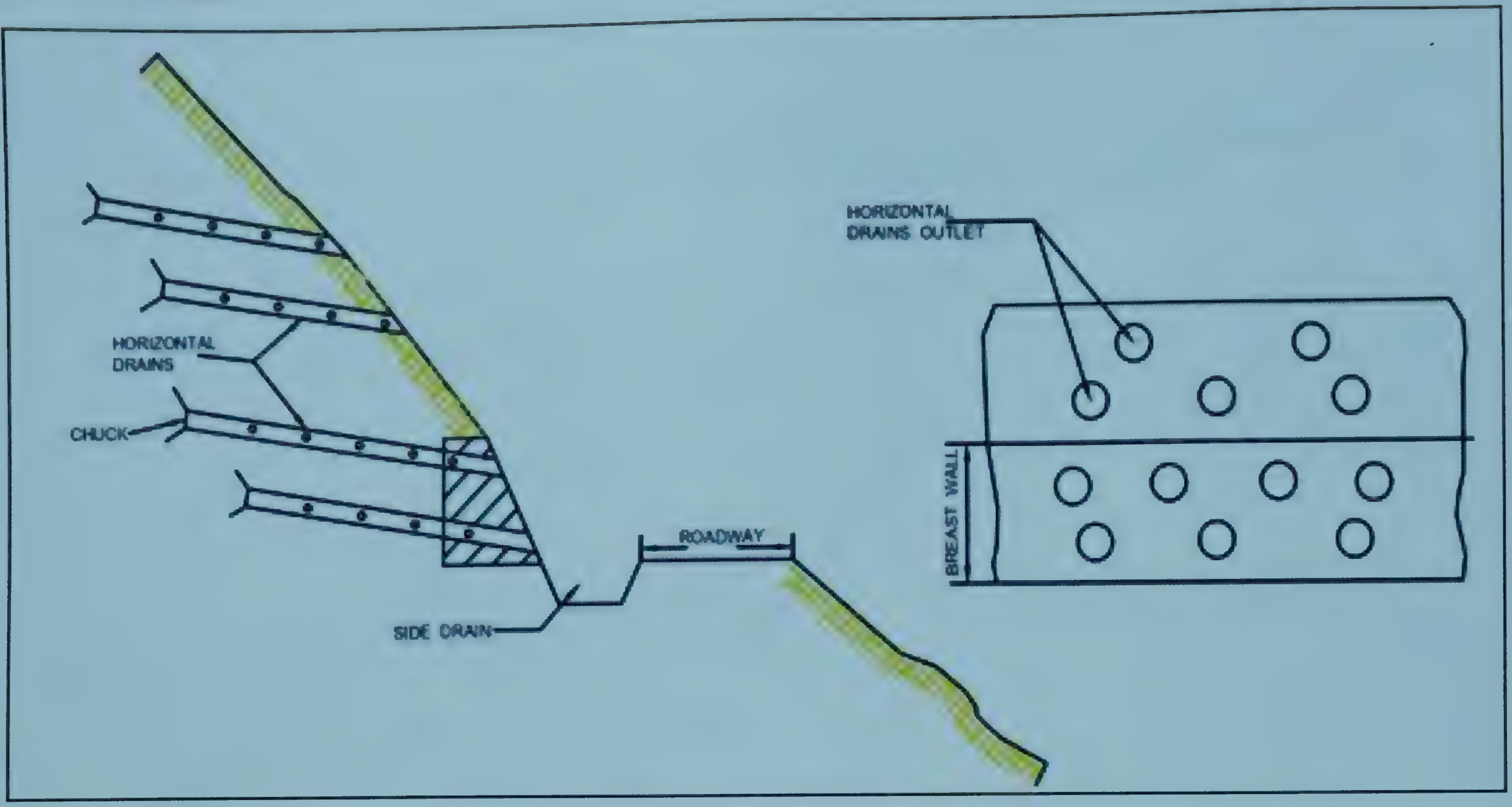


Fig. 4.6 Horizontal Drain

Horizontal drains enable an overall improvement of the stability of the slopes by reduction in the level of the water table. Reduction in water table results in decreased pore water pressure at the base of the slide surface. The relationship can be worked out easily, for a given slope. In general, the disposition of horizontal drains should be so arranged that the desired decrease in piezo-metric levels occur.

a) Horizontal drains can be used in a wide variety of soil types including weathered and fragmented rocks.

b) In general, horizontal drains shall be made up of 50 mm to 100 mm diameter perforated/ slotted corrugated PVC / HDPE pipes with the upper two-third portion of the pipe is perforated/ slotted. The specifications of pipes shall meet the specifications for corrugated pipes (with or without perforations) shall conform to IS-9271 and/or IS 16098 Part-2. The specifications for plain PVC/ HDPE pipes shall conform to IS 4984. The type of pipe to be used shall be decided depending on flow/site conditions. The pipes are installed in pre-drilled boreholes at a negative gradient of 5 to 15 degrees to the horizontal into a hill or an embankment for removing groundwater of the sub-soil with poor permeability. It is also recommended to wrap the pipe by a suitable nonwoven geotextile so that the soil particles are prevented from entering into the perforations/ slots thereby reducing the possibility of its clogging.

c) As a general rule, long drains with larger spacing are more efficient than short drains with less spacing. Moreover, the smaller/flatter the slope angle, the longer should be the drain. PVC pipe drains should not exceed 40 m in length; for longer drain stiffer pipe materials (stainless or galvanized) is recommended. If the slope profile consists of heterogeneous soil and/or fractured rocks, the length of the horizontal drains must traverse as many as permeable materials as possible.

d) Sub-surface drainage by horizontal drains represents a more effective solution compared to the prohibitive cost of adopting other conventional corrective measures. In situations where excess hydrostatic pressure is the main cause of slope failure.

e) Adequate geological and geotechnical studies should be conducted to locate the water table determine the material properties and evaluate the benefits from horizontal drain installation.

f) In critical slopes the horizontal drain may be placed behind retaining structures like breast walls and the discharge allowed to collect by draining across the wall into side drain.

(C2) Deep Trench Drains

(i) Deep trench drains can also be used for the purpose of sub-surface drainage. A typical sketch is given in **Fig. 4.7**. These are generally limited by practical consideration, to those locations where water can be intercepted at depths less than 5 to 6 m. Such effective drains consist of a permeable gravel core, surrounded by a filter fabric like nonwoven geotextile to prevent clogging. Nonwoven geotextile shall confirm the MoRTH Specifications – Section 700. These can be adjusted to varying conditions of soil and groundwater. The gravel size is either 16-32 mm or 36-70 mm to ensure a sufficiently high void ratio. The average amount of material needed per meter of drain length is about 1 m^3 of gravel and 5 m^2 fabric.

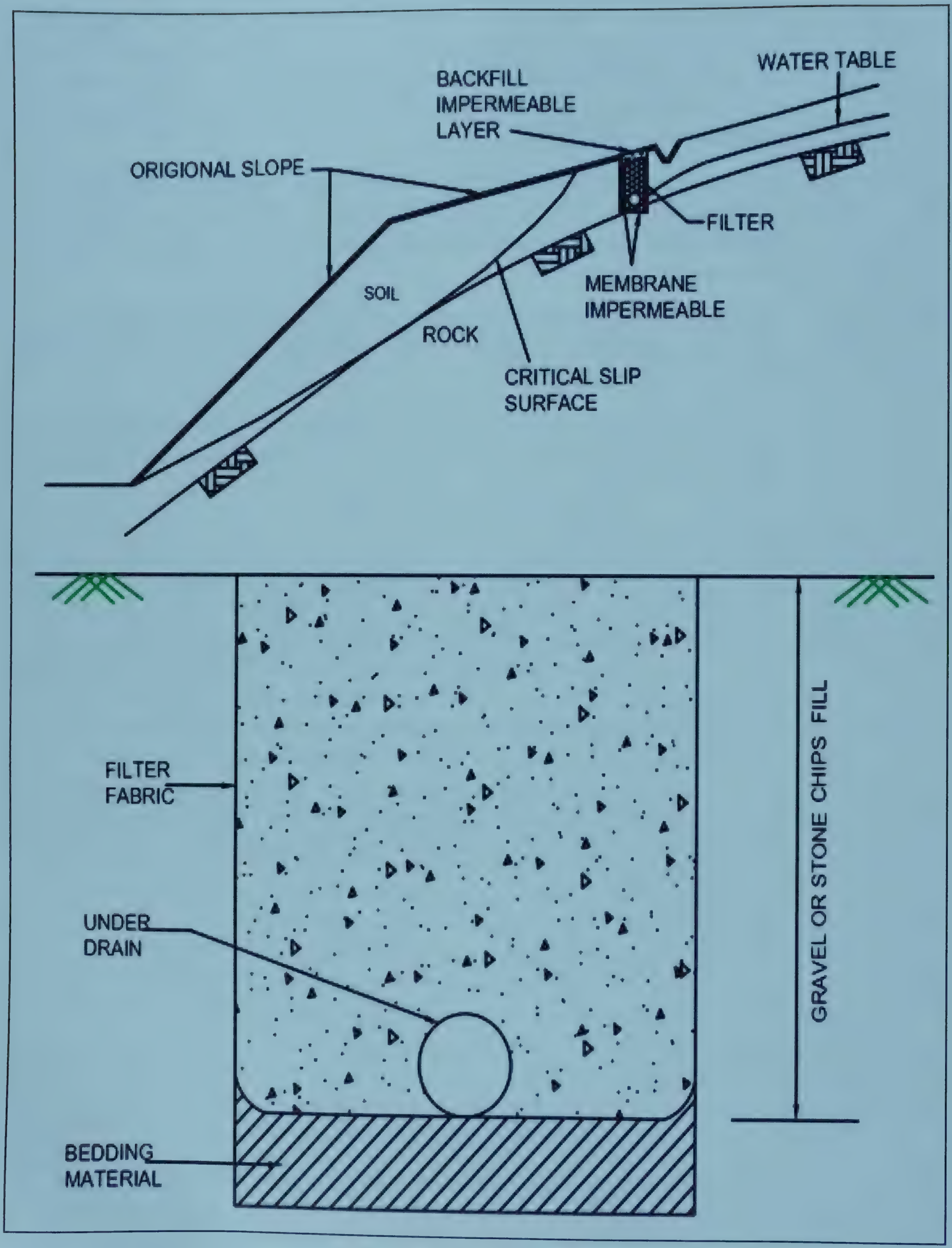

WATER TABLE
BACKFILL
IMPERMEABLE
LAYER
ORIGIONAL SLOPE
FILTER
MEMBRANE
IMPERMEABLE
SOIL
ROCK
CRITICAL SLIP
SURFACE
FILTER
FABRIC
UNDER
DRAIN
BEDDING
MATERIAL
GRAVEL OR STONE CHIPS FILL

Fig. 4.7 Deep Trench Drain

(ii) In addition to the above, a lined surface drain may also be constructed for the upper part of the trench drain serving purpose of catch water drain, which will cater both surface drainage as well as subsurface drainage. Such drains are connected to the nearest natural water course or chutes. The method is illustrated in **Fig. 4.8.**

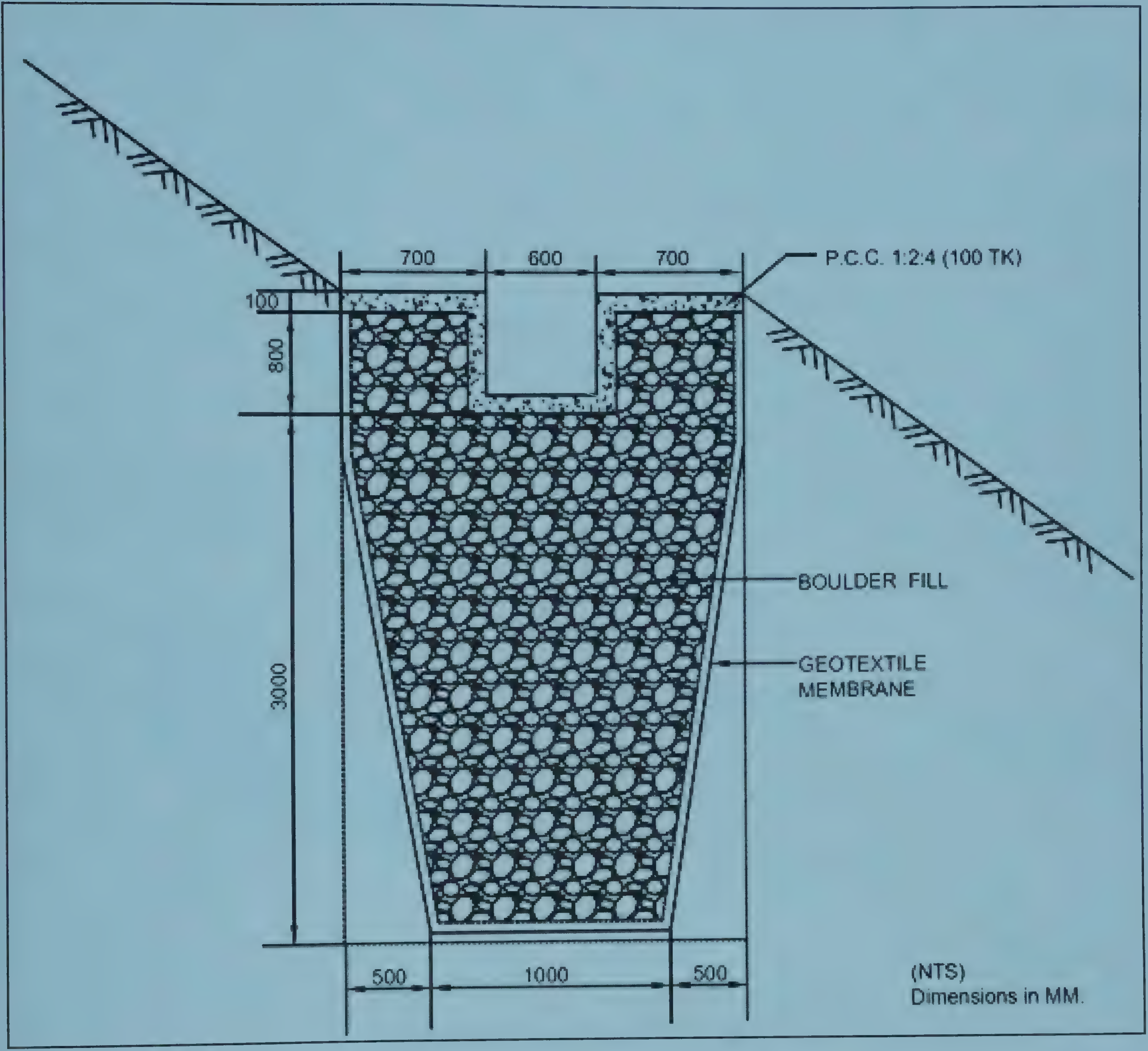

700
600
700
P.C.C. 1:2:4 (100 TK)
100
800
3000
BOULDER FILL
GEOTEXTILE MEMBRANE
500
1000
500
(NTS)
Dimensions in MM.

Fig. 4.8 Cross Section of Trench cum Surface Drain

(iii) The individual trench drain is to be made in short Sections 5 m to 10 m long. After the trench is excavated the filter fabric is spread out, trench is filled with gravel up to the top water bearing layer and then the fabric is overlapped. Control shafts at the junction of drains are installed in order to check the time dependent flow of water in the individual drains. Pipes may be required to feed the water into the control shafts at some locations.

(D) Removal of overburden to enhance Slope Stability/Reduction of Weight

If relocation or realignment of a proposed highway is not possible, either complete or partial removal of the unstable material should be among the alternative design considerations. This method will contribute to increase stability of the soil mass beneath a slope. The main methods used for prevention or correction are removal of head of the slide, lowering of the grade line, flattening or benching of slopes and complete removal of all unstable material. The required quantity of material to be removed must be carefully estimated by stability analysis, using laboratory and field data. Removal of head of a slide aims at unloading or taking away a relatively large quantity of material from the head of a landslide thereby reducing the activating force. The method is illustrated in **Fig. 4.9**.

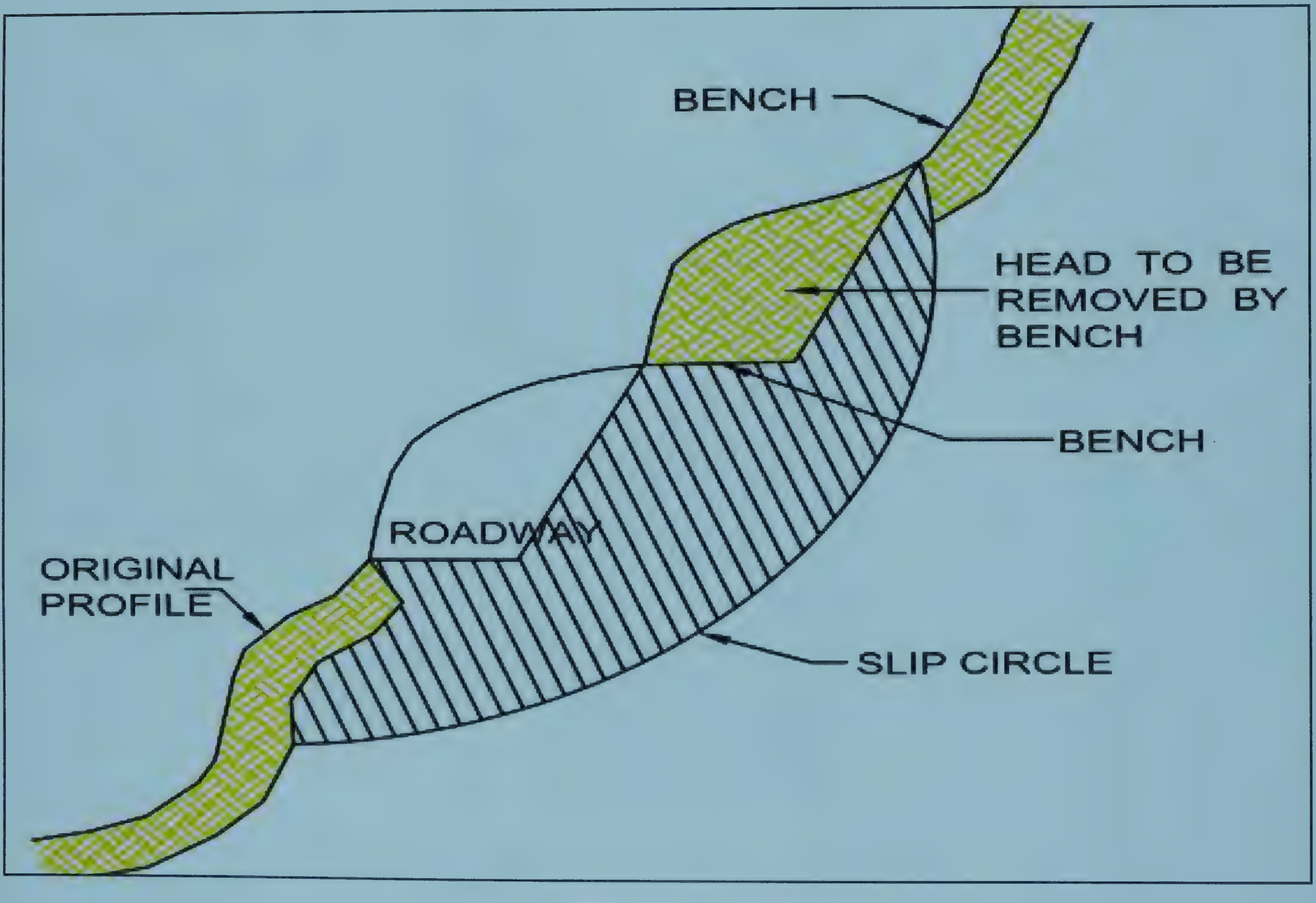


Fig. 4.9 Reduction of Weight

(E) Removal of Potentially Unstable Rock (Scaling and Trimming)

i) Stabilization of rock slopes can be accomplished by the removal of potentially unstable rock. In general, rock removal is a preferred method of reduction in driving force and the work will eliminate the hazard, and no future maintenance is likely to be required. However, the rock should be removed only where it is certain that the new face will be stable, and there is no risk of undermining the upper part of the slope.

ii) It would be safe to remove the outermost loose rock, provided that the fracturing was caused by blasting and only extended to a shallow depth. However, if the rock mass is deeply fractured, continued scaling will soon develop a cavity that will undermine the upper part of the slope. Removal of loose rock on the face of a slope is not effective where the rock is highly degradable, such as shale. In these circumstances, exposure to a new face will just start a new cycle of weathering and instability. In all such cases, these operations should be observed and carefully controlled to prevent the creation of unsupported or overly steep slope areas.

iii) Stability of rock slopes can be achieved by removing weight from the upper part of the slope and unstable material as shown in **Fig. 4.10** and also by flattening and benching of slopes. Overhanging rock is either removed or trimmed back to a stable part of the face. Scaling operations are usually carried out by workers suspended by ropes or other means. These operations can be time-consuming and expensive (sometimes dangerous) and on active slopes may need to be repeated every few years, or as needed. Scaling is highly skilled work and can be dangerous; scaling crews should be trained, and the work should be performed under supervision expert/ professionals. For definitions, uses, types of scaling and its limitations, reference may be made to **Chapter-5** of FHWA-CFL/TD-11-002.

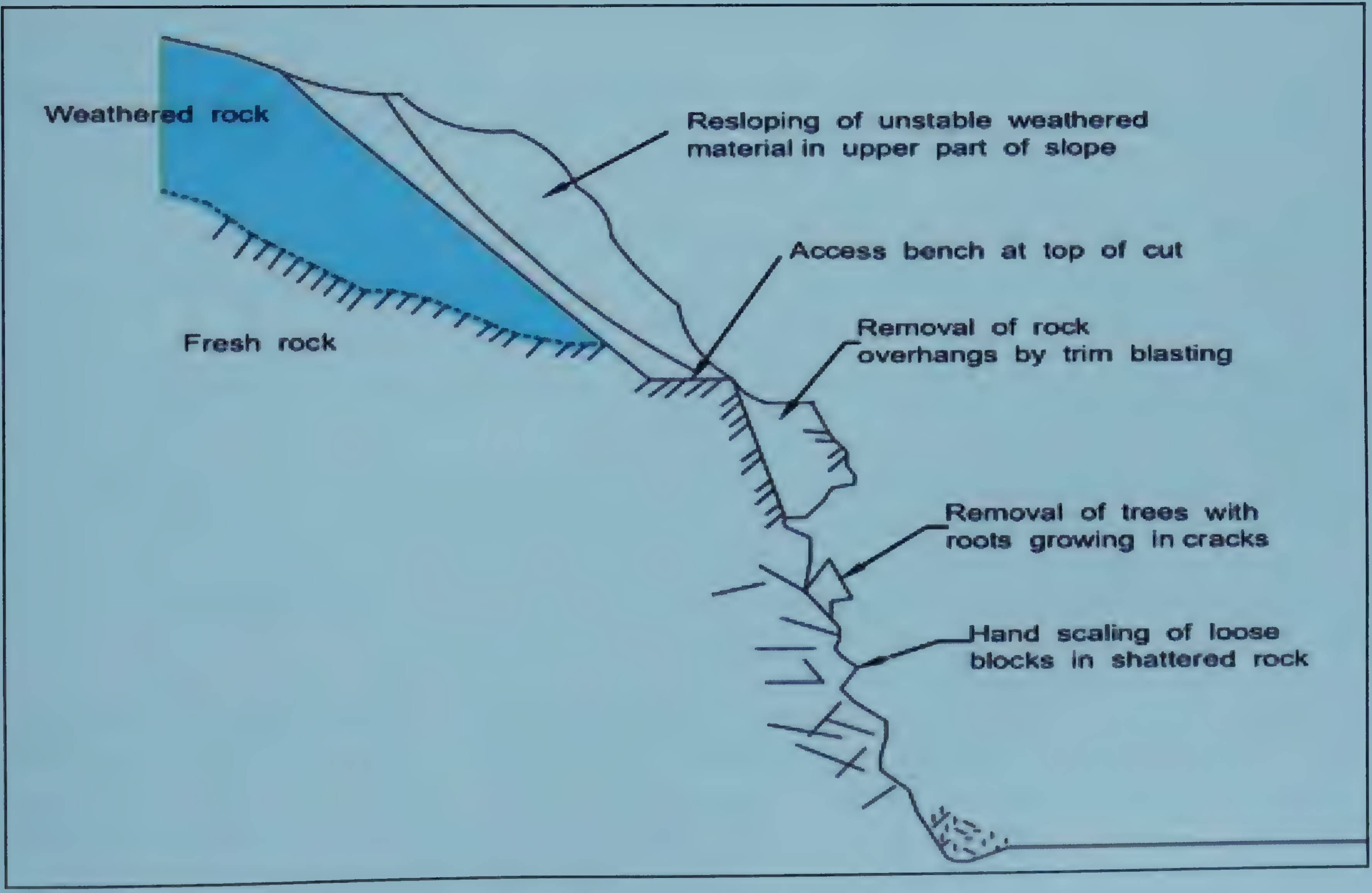

Weathered rock
Resloping of unstable weathered material in upper part of slope
Access bench at top of cut
Fresh rock
Removal of rock overhangs by trim blasting
Removal of trees with roots growing in cracks
Hand scaling of loose blocks in shattered rock

Fig. 4.10 Rock Removal Methods for Rock Slope Stabilization

iv) Slope flattening and benching reduces the driving forces on a potential or existing slide. Slopes constructed with benches or berms are considered preferable to equivalent uniform straight slopes. Benching produces increased stability by dividing the long slope into segments of smaller slopes connected by benches. The width of benches should be adequate to enable the slope segments to act independently. Benches are useful in controlling instability if they are properly designed and provided with paved drains. Slope flattening by benches is illustrated in **Fig. 4.11**

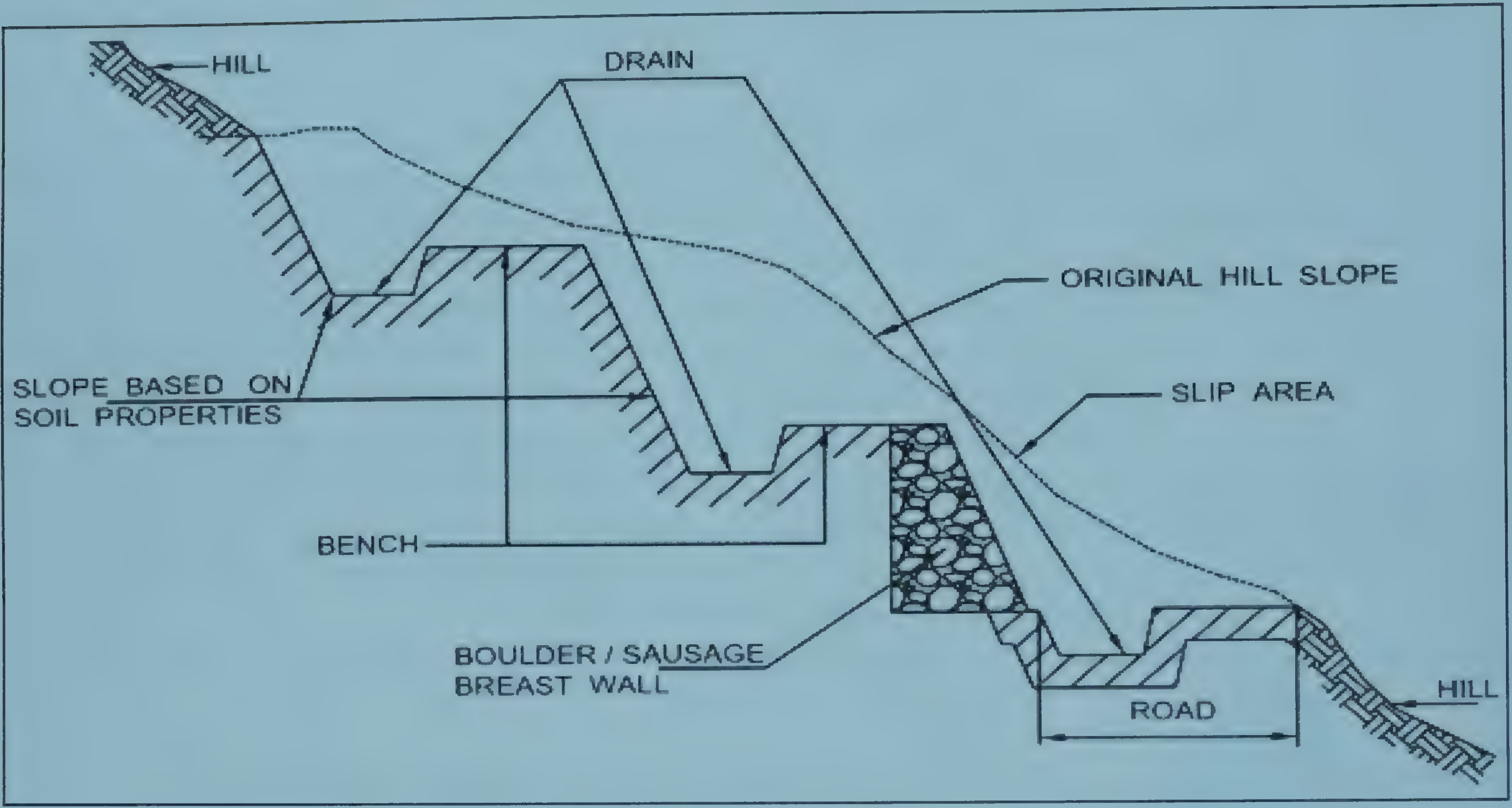


Fig. 4.11 Benching

Important Note: *The excavation shall always be done from top to bottom to ensure slope stability. In no circumstance the cutting shall be initiated from toe of the slope. The final cut slope profile must be checked for global stability for a minimum factor of safety of 1.3 for static and 1.1 for seismic.*

Adequate drainage and erosion control measures must be designed to ensure long term performance of the cut slope.

It is not always possible to do excavation/ or the methods described above because of difficult access to the upper part of the slope or large volume of material that would have to be removed for measures to be effective or the environmental problems deriving from the dumping of excavated material or due to pre-existing installation in this area. In such cases slope stabilization shall be done by other alternative methods described in the following sections.

v) Cutting of slopes in rock: The quality of rock which is commonly designated by qualitative index or RQD can be of help to the engineers in qualitatively assessing the overall stability of slope. The relation between RQD (Kraatx, 1964} and the description of rock quality is given in **Table 4.1**.

Table 4.1 RQD vs Description of Rock

IS 12070-1987 AMR	RQD (per cent)	Description of rock quality
Rock Mass Rating		
0-20	0-25	Very poor
21-40	25-50	Poor
41-60	50-75	Fair
61-80	75-90	Good
81-100	90-100	Excellent

$$RQD = \frac{L_c}{L_a} X\ 100$$

where

$L_c = Total\ length\ of\ intact\ pieces > 100mm\ long$

$L_a = Total\ Length\ of\ core\ advance$

If the hill slope under consideration has no major fault planes or shear zones nearby, RQD can have a significant influence on the stability. In general, a tendency exists for adoption of experience-based rule of thumb procedures when dealing with stability of rock slopes.

However, it would lead to safer and economical rock slopes if proper design methods are adopted to evaluate the stability of rock slopes as well. Rough guide for the slopes or cuts in rock is given in **Table 4.1**. Further, in adopting this table, caution must be exercised and factors such as the influence of dip in relation to the inclination of the slope face, the nature of joints etc. must be kept in mind.

Several methods are available for the control of rock slope instability. The various methods by which rockslides/rock-falls can be controlled for protection from rock-fall hazards are listed below:

F) Control of Erosion of Hill Slopes

i) Hill slopes are subject to erosion from flowing water leading to the foot of hill slopes. Cutting of forests increases the erosion potential. The debris carried away by the flowing water may damage the slopes downhill and choke the streams. It has also been found that, erosion, if unchecked, tends to produce mass movements in the shape of landslides. Thus, the slope degradation by surface erosion has a multiplier effect. It is more economical to control the damage at the initial stage itself.

ii) Majority of slope stability problems in hill areas have their origin in cumulative erosion of hill slopes. It has been repeatedly observed that the combination of rainfall, soil type and slope conditions in these areas favour the occurrence of shallow erosion type of landslides. Plantation of grass and shrubs to restore the vegetative cover has been found to be success ful in arresting this type of mass movements. The presence of vegetative cover is beneficial to the stability of slope in a number of ways as enumerated below:

a) Surface erosion will be controlled. If some remains unchecked, there is a high probability that the erosion may extend deeper and wider and eventually endanger the stability of the slope.

b) Infiltration of water into the slope will be controlled thereby reducing the build-up of pore pressure. Decrease in factor of safety is directly proportional to the increase in pore pressure.

iii) Growth of vegetative cover and the spread of root-network to an approximate depth of 0.5 to 1.0 m depth help to improve the overall stability of the slope as brought out by field experiments carried out on different hill slopes for erosion control. Certain methods are described below

F1) Asphalt Mulch Treatment

(i) Field trials have indicated that the asphalt mulch technique is effective in controlling erosion of hillslopes by providing suitable vegetative turfing. For this treatment, the proposed slope area is prepared into vast seed beds by leveling of the top re-grading or reshaping and finally raking the topsoil about 2 cm thick. If the soil is infertile or slightly acidic. Calcium ammonium nitrate is applied at the rate of 50 kg. per 1000 sq.m. in solution. The root slips or locally available grasses are dibbled 15 to 20 cm apart root to root and row to row. An asphalt emulsion (mulch) of a specified grade is then spread by a suitable sprayer. The optimum rate of application of the emulsion is 0.9 liter per sq.m i.e. just a thick film.

(ii) The asphaltic film gradually disintegrates and its place is taken by a carpet of green vegetation and the deep-rooted species or grasses clovers etc. The advantages of this technique are:

(iii) Susceptibility to erosion is cut down.

(iv) The moisture content as well as the nutrients in the soil mantle are conserved.

(v) The soil temperature is raised by absorbing light rays, promoting the emergence and growth of any saplings.

(vi) This method, if done just before the monsoons, the increased moisture content due to rains automatically helps in the growth of saplings.

F2) Dry Seeding

Dry seeding is done with rotary disk and air-blown seeders. These methods are less costly than hydraulic seeding but are limited to rough soil surfaces and gentler slopes. Rotary disk seeders spread seed and fertilizer by centrifugal force. The simplest seeder is the hand-held seeder. Air-blown seeders use air to blow or shoot seed and fertilizer up to a distance of 5 to 8 meters. Equipment can be adapted for motorized vehicles. Till the establishment of vegetation, the slope is susceptible to erosion and may result in washing away of seeds and seedlings. In such circumstances, a protective cover on the soil is required which can resist soil erosion, retains runoff and facilitates the establishment of vegetation on the surface. Such systems can be broadly classified in two (a) Rolled Erosion Control Products (b) Hydraulically Applied Erosion Control Products.

F3) Rolled Erosion Control Products (RECP)

It can be either biodegradable mats like coir, jute geotextile, etc. or Erosion Control Blanket (ECB). Even though the RECP can be utilized to provide a cover, provision of it alone won't help to bring vegetation without adequate measures. ECBs shall be applicable only for very gentle soil slopes (geo-technically quite stable) and where rainfall intensity is comparatively less. To ensure the proper functioning of RECPs, soil surface needs to be smooth graded or else it will leave voids behind loose erosion control mat which will make the growth of vegetation difficult. The selection systems of the erosion control products shall be in accordance with the specifications mentioned in Table 13 & 14 of MoRTH 700. Construction procedure is given in IRC: 56.

F4) Hydraulic applied Erosion Control Products (HECP)/Hydro-Seeding/Hydro-Mulching

Hydraulically applied erosion control is a process where seed and any combination of fertilizer, lime, bio-stimulant, moisture retention polymer, tackifier, and other additives are combined with water and a hydro-seeding mulch (HECP materials) to form a slurry. These ingredients are mixed in a Hydro mulcher machine which contains a mechanical agitation system that creates and maintains a homogenous slurry and sprayed over prepared ground in a uniform layer. In general, HECPs require less soil preparation, fast and efficient on larger jobs, it can be applicable for rocky or uneven soils or sites which are difficult to access.

F5) Slope Protection using Geo-cells

On natural slopes where vegetation may be difficult to establish, geo cells may be adopted as an erosion protection system. Geo-cells are 3-dimensional cellular confinement system, fabricated from ultrasonically welded HDPE strips that are expandable on site to form cellular structures. The HDPE material required to be used for geo cells shall contain minimum 2% carbon black for UV resistance. The walls of the cells are perforated for migration of nutrients with pore water. The perforations along with the textured surface of the cell walls help retain the infilled topsoil. The cell depth of geo-cell for erosion protection generally ranges from 75 – 150mm, but higher depth may be considered as per specific site requirements. Geocells are placed in position over a reasonably dressed surface, expanded and placed in position by J hooks or stakes, spiked into the ground. The geocells prevent the soil from slippages and encourage vegetation growth. The system reduces the water runoff velocity down the slope surface. Geo-cells in-filled with coarse granular material can be considered where vegetation growth is difficult. Suitable geotextile conforming to MoRTH 700 & IRC: SP:59 should be adopted as filter media behind geo-cells.

F6) Slope Erosion Protection using Gabions and Mattresses

Gabions and mattresses can be successfully used for erosion protection of gentle & steep slopes as per IRC 56 for slopes subjected to heavy erosion especially near to water bodies. Gabions & mattresses as porous gravity weights can effectively sustain the eroding slope and also preserve their natural look without the need of any tree cutting or roots removal, thus providing eco-compatible and free draining solutions. Gabions & Mattresses shall meet the specifications mentioned in IS 16014 & MoRTH: Section-2500.

(G) Selection Criteria of Erosion Control System

The selection of the erosion control measures shall be made based on considering the following factors.

(G1) Erosion Control Effectiveness and Functional Longevity

Erosion control effectiveness is the ability of an erosion control material to protect the soil from the kinetic energy of splash erosion and overland flow caused by rainfall impact. Functional longevity is a measure of how long the erosion control material can be expected to adequately protect the seed and soil from splash and overland flow erosion caused by rainfall. It can be correlated with percent effectiveness.

G2) Selection of Appropriate Technique

When selecting the appropriate erosion control techniques, many additional factors shall be evaluated including slope gradient, rainfall intensity, soil type/texture, soil fertility, functional longevity, slope length, soil preparation, expected vegetation. As the slope length and gradient increase, the water travels at a faster velocity, exerting larger erosive forces on the soil. Therefore, for steeper and longer slopes, a higher performing product is warranted to adequately stabilize the soil and increase factors of safety.

G3) Vegetative Establishment

It is a measure of the ability of an erosion control material to encourage seed germination and plant growth. Reference shall be made to ASTM D7322 for evaluation. The larger the value for the vegetative establishment, the faster the desired level of vegetation may be achieved. This property is highly dependent on the water-holding capacity of the medium. Reference shall be made to ASTM D7367 for evaluation of water-holding capacity.

G4) Agronomic Testing Requirements

Agronomic soil analysis shall be conducted to find out Soil pH to determine soil reaction and neutralization requirements, presence of soluble salts to determine total salts content in soil solution, excess Carbonate, Organic Matter Content, Macronutrients (N, P, K, Ca, Mg, Na, S) and Micronutrients (B, Cl, Cu, Fe, Mn, Zn) to determine nutrient element availability, Other elements (Al, Na),Trace elements and heavy metals (As, Cd, Co, Cr, Cu, Mn, Pb, Ni) to determine the Toxicity, Cat-ion Exchange Capacity, Percent Base Saturation Sodium.

G5) Type of Seeds

A combination of two to five species is the normal grass-legume mix used for erosion control. Suitability of seeds depends on soil type, climatic conditions, species compatibility, and species replacement. Local conditions will vary, and no universal type of grasses or legumes can be recommended. The types of vegetation can vary from locality to locality, and it is best to get advice from locals who are familiar with local growing conditions. Annual species are good for short term protection. Perennial species (live more than one year) must include plants with runners, stolons or rhysomes to protect the soil.

G6) Bally Benching

Bally benching is used for control of surface erosion on slide areas as well as for arresting shallow movement of the top mantle of slide mass. This technique can also be used effectively in preventing the deepening of gullies/chutes, caused by the eroding action of flowing water. During rains, the surface flow generally results in gully formation on slopes. Such gullies, if allowed to deepen, induce instability in the slide slopes which eventually fall/slide down and help the gullies to widen. Latter this phenomenon can result into a potential landslide. Barrier/bench system helps in densification of soil material surrounding the ballies thereby increasing the strength of the slope, prevents the shallow movement of the loose mantle and retards the speed of surface water responsible for gully formation. Typical arrangement is shown in **Fig. 4.12**.

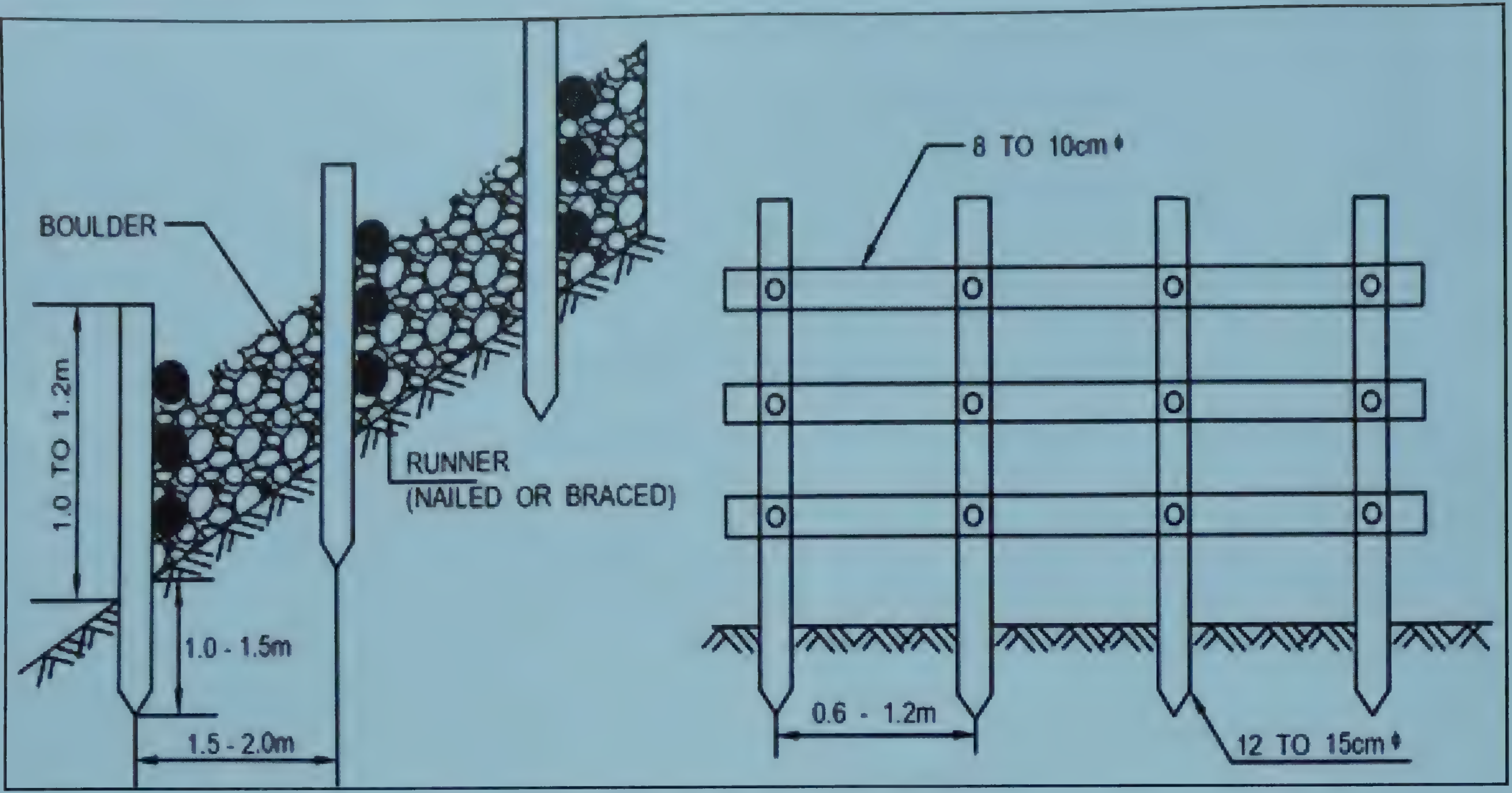


Fig. 4.12 Bally Benching

G7) Sealing of tension cracks

(i) Tension cracks are usually present in all slopes affected by instability. These are produced due to the strains caused by the incipient mass movements and are thus indicators of impending instability. Cracks have been observed with widths ranging from a few millimeters to as much as 100cm or more. These open cracks serve as a direct path for the infiltration of surface run-off water, enabling it to reach deep into the slope mass, thereby further decreasing the factor of safety of the slope. It is, therefore, important to seal the tension cracks effectively to prevent any ingress of water.

(ii) The procedure adopted in sealing the tension cracks is that a trench of about minimum 50 cm depth and 50 cm width should be cut all along the length of the cracks. The excavated material should be mixed with water to make up to the optimum moisture content for filling the trench. At first the deeper parts of the cracks should be filled up by rolling and tamping thoroughly with crow bars. The filling of the trench should be done by spreading the wet soil at O.M.C. in layers of 15 cm and compacting by hand rammers.

(iii) The top layer should be finished such that the original shape/gradient of the 'Slope is retained to the maximum possible expert. The filled-up surface over the tension crack should then be made waterproof by evenly spraying it with bituminous cutback of following composition viz. Bitumen (1.0 kg), Kerosene (0.6 kg) and Paraffin Wax (0.01 kg). The bitumen should be first heated to about 110°C and removed away from the flame and other two components added. The mixture may be sprayed with a garden sprayer, at an average rate of 0.2 kg per sq. m.

Sealing of tension cracks should be considered as a regular maintenance measure and not as a onetime remedial measure. The slopes should be inspected before the onset of monsoons and tension cracks sealed. As may be seen from above, sealing of tension cracks is an inexpensive measure and the returns in form of improved slope stability are very high as observed at a number of slide locations in practice.

4.3.3 *Increase the Forces Resisting the Movement*

There are many methods available to increase the resisting forces of a slide surface. These methods can be grouped according to two basic principles. Restraining structures such as counterweight fills, buttresses, pile system and anchor system are the methods which apply a resisting force at the toe of the sliding mass. Other methods such as sub surface drainage, slope treatment, slope stabilization, etc. are essentially methods for increasing the strength of the material in the failure zone. **Fig. 4.13** shows a typical sketch showing various rehabilitant measures such as removal of overburden at first instance or protection of overburden with nails/ anchors with secured drapery system in case removal is not possible for uphill side is shown in **Fig 4.13.** For downhill side, measures such as lined drainage, reinforced soil system with semi perforated PVC pipe wrapped with nonwoven geotextile and erosion control measures etc. are shown. It may please be noted that the sketch is only illustrative, designer may adopt other measures based on geotechnical investigation etc., as per site conditions.

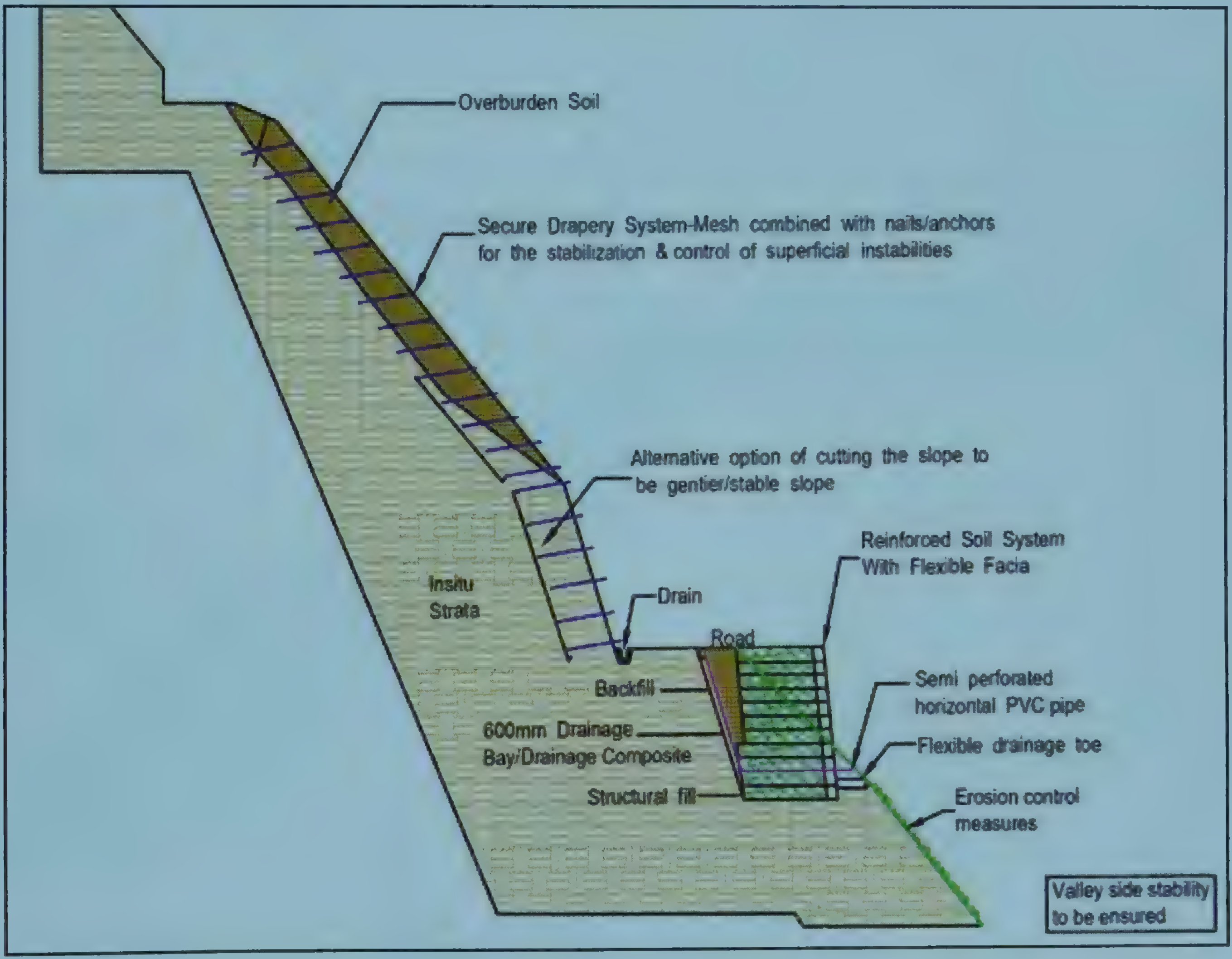

Overburden Soil
Secure Drapery System-Mesh combined with nails/anchors for the stabilization & control of superficial instabilities
Alternative option of cutting the slope to be gentler/stable slope
Reinforced Soil System With Flexible Facia
Insitu Strata
Drain
Road
Backfill
Semi perforated horizontal PVC pipe
600mm Drainage Bay/Drainage Composite
Flexible drainage toe
Structural fill
Erosion control measures
Valley side stability to be ensured

Fig. 4.13 Some Typical Rehabilitation Measures to Control Slide

4.3.3.1 *Counterweight Fills and their Design*

(i) Counterweight fills provide sufficient dead weight near the toe of the unstable slope to prevent the movement. These provide an additional resisting component thereby increasing the factor of safety against failure. The counterweight fill should be placed on a stable foundation layer with adequate depth. These must be designed to resist the driving forces, i.e. overturning, shearing and sliding at or below the base. It must also be ensured that the counterweight fill itself is stable during the period of construction as well as during the design life of the structure. The counterweight fills at the toe of the unstable slope can take various forms such as toe walls, retaining walls, reinforced soil structures etc.

(ii) In general, cuts and fills have better effects in correcting deep seated slides where the steep slip surface falls near the crown. However, it is suggested that whenever the modification of slope profile resorting to cutting or filling, is contemplated an analysis of its effect on the factor of safety of the slope be carried out. **Fig. 4.14** illustrates counterweight fill on cut and fill method to increase stability factor.

(iii) In certain situations, it becomes difficult to cut the slopes and they are required to be maintained in the existing gradient. Under such situations, they can be contained at the existing slope by using the technique of anchoring/nailing coupled with various surficial stabilization measures.

(iv) The provision of drainage measures also improves the internal shear strength of the sliding mass and shall be used wherever feasible.

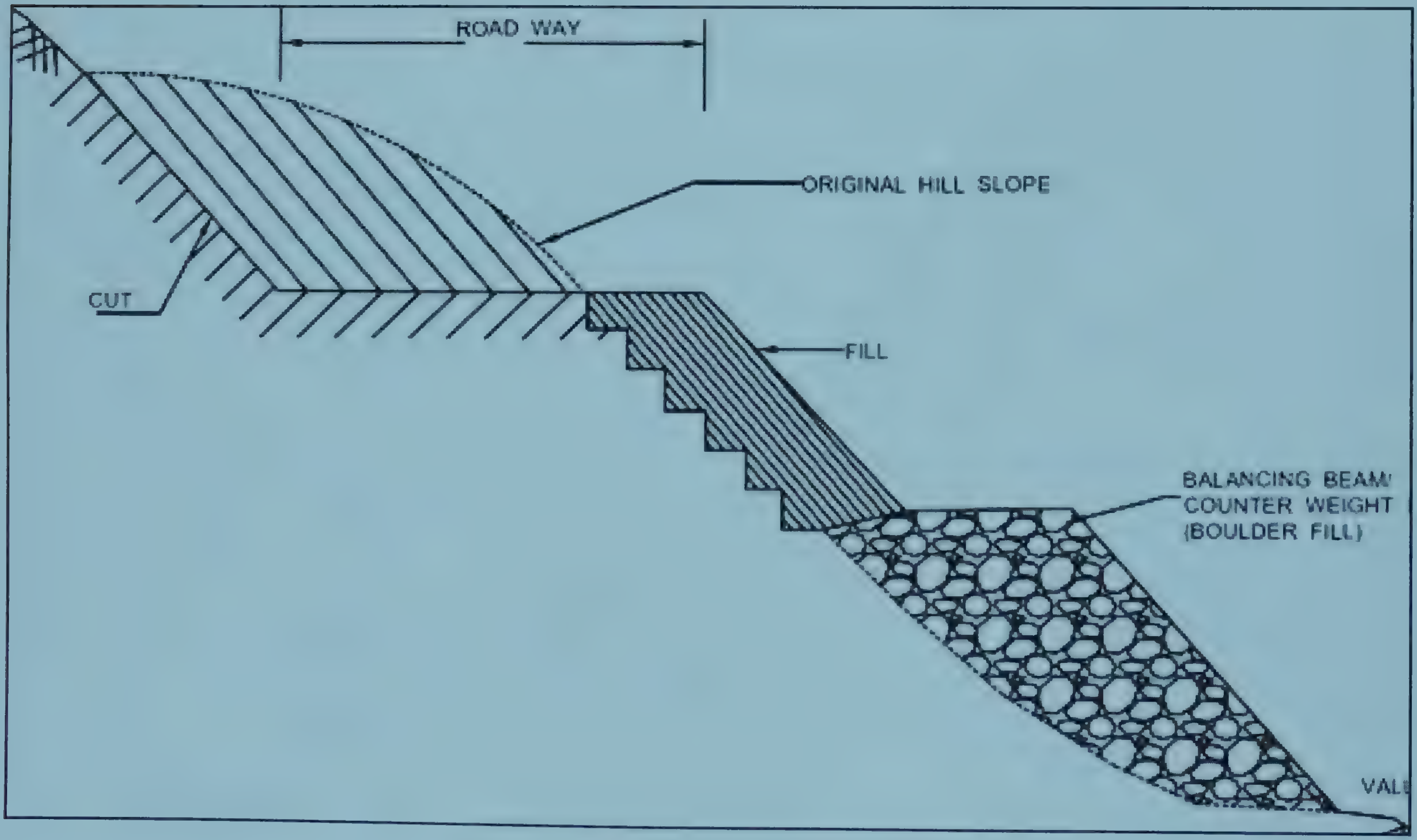


Fig. 4.14 Counterweight Fill

4.3.3.2 Retaining Walls

During road formation involving cutting, the natural slope get disturbed. Structures to support the downhill side unstable area or fills are called retaining walls. They can be constructed in stone masonry, cement concrete, reinforced cement concrete, mechanically woven gabions, wooden/ timber/poles etc. depending on ground condition. Reinforced soil structures – reinforced soil walls or reinforced soil slopes, shored MSE walls, anchored retaining walls etc. are also now being used to protect the unstable slopes.

a) Generally, for hill slopes with gentle slope, retaining walls may not be required. But the moment cutting of hill slope is resorted for construction of road/ drainage work etc., the slope gets disturbed and shall be protected from disturbance in future. For steeper slopes, relative economy of cost of earth cutting and retaining wall has-to be compared. From stability point of view, full hill cutting should not be preferred until unless hard rock is encountered instead a balance in both cutting and filling shall be preferred subject to its stability considerations of cutting as well as filling. The final geometry shall be decided based on overall stability checks, highway alignment design and overall cost. Construction of retaining structures in the form of reinforced soil structures or shored MSE structure on valley side can now be considered more suitable solution for hill road construction.

b) Other situations requiring the construction of retaining walls/steep slopes are:

   i. Places where the valley side surface gets saturated in the monsoons and is likely to result in slip taking a part of road with it.

   ii. Places where undercutting by a stream or other water course causes damage to the valley side and the road.

   iii. In valley point, where water flows-over the road.

   iv. To achieve width of roadway, where cutting into hill is not stable or economical or has to be restricted due to other reasons.

4.3.3.2.1 Classification:

The retaining walls can be broadly classified into rigid gravity retaining walls and flexible gravity retaining walls.

A. Rigid Gravity Retaining Walls

Gravity retaining wall depends on its self-weight only to resist lateral earth pressure. Commonly, gravity retaining wall is massive because it requires significant gravity load to counteract soil pressure as shown in **Fig. 4.15.** A hill road masonry retaining wall is a gravity wall which shall be considered safe under the expected conditions of loading, if following conditions are satisfied.

- It shall be safe against sliding and overturning
- Shearing stress shall be less than shearing strength available and
- The pressure at the toe shall remain less than the safe bearing capacity of the foundation material

Based on the mechanism, type of construction, strength and service required, the rigid retaining walls may be further classified as:

i. Rigid gravity retaining structures - Brick/Uncoursed random (UCR) /Random Rubble (RR) stone masonry wall, concrete retaining wall,

ii. Rigid RCC Cantilever retaining wall

iii. Rigid RCC Counterfort retaining wall

iv. Rigid RCC Diaphragm walls

v. Concrete crib works

vi. Rough dry stone with lime concrete/cement concrete foundations if necessary.

vii. Rough dry stone with strengthening bands of stone in lime/cement.

viii. Masonry in lime mortar, or lime with pozzlona or cement concrete foundations.

ix. Masonry in cement mortar on cement concrete foundations.

1. Point (vi & vii) apply to ordinary retaining and breast walls, not impinged upon by floods and not required to hold water and points (viii & ix) apply to abutments and important retaining walls or portions thereof.

2. For the selection of a type of retaining walls for hilly areas, refer to IS 14458 (Part-1). For design of retaining/breast walls, refer to IS 14458 (Part-2). For construction of dry-stone walls, refer to IS 14458 (Part-3). For Construction of banded dry-stone masonry walls, refer to IS 14458 (Part-4). For construction of cement stone masonry walls, refer to IS 14458 (part 5). For design of RCC Cantilever retaining walls, reference shall be made to IRC HRB 15.

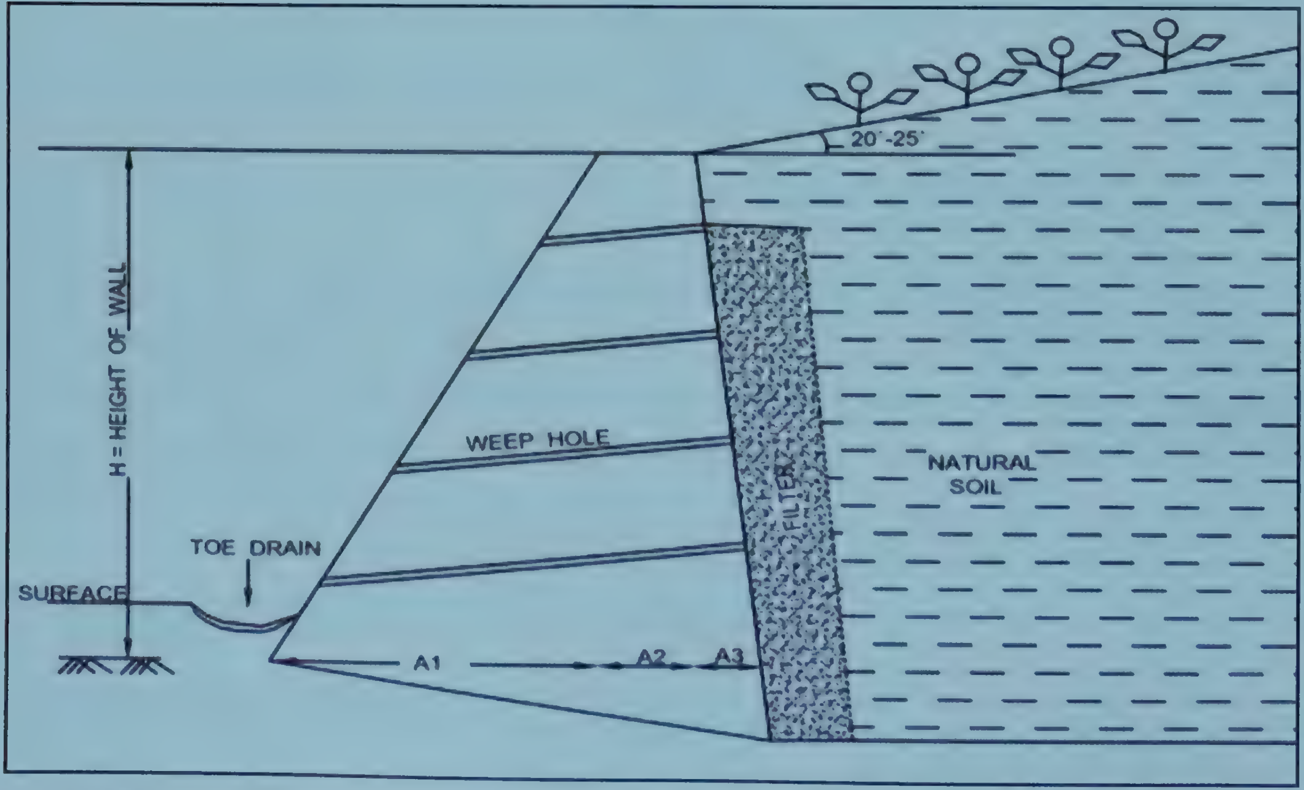


Fig. 4.15 Typical Section of Gravity Retaining Wall with Backfill Material

A1. Dry-stone Masonry/Banded Dry-Stone Masonry Retaining/Breast Walls

(a) Subject to structural safety and stability considerations, Retaining/Breast walls up to 6 meters height in Random Rubble (RR) stone masonry with 1:6 cement mortar (1 cement: 6 coarse sand) can be provided. Beyond 6 m height Random Rubble stone masonry retaining/breast walls shall be avoided.

(b) Subject to structural safety and stability considerations, Breast Walls (Not retaining walls) up to 6 m height as shown in fig below in Random Rubble (RR) dry stone banded masonry in panels can be provided. The panels of RR dry stone masonry shall be enclosed within a band on all the sides. The center to center spacing of the band shall not be more than 3.0 meters in longitudinal as well as in cross directions. The Band width shall not be less than 45 cm. The band shall be constructed in full thickness of the section of wall either with RR stone masonry in 1:6 cement mortar (1 cement: 6 coarse sand) or with cement concrete 1:3:6 (1 Cement: 3 coarse aggregate: 6 stone aggregate nominal size 20 mm).-Beyond 6m height Random Rubble dry banded Masonry breast walls shall be avoided.

(c) In RR Stone Masonry in cement mortar as well as RR dry stone banded masonry, proper bond stones @ one bond stone per 0.5 square meter (0.75 m x0.75 m) or part there of wall face area in full thickness of section of wall shall be provided. Precast /cast in-situ cement concrete of 20 cm x 20 cm cross section in full depth with nominal reinforcement shall be provided. During the progress of layers of wall at the end of each day's work and while terminating/restarting each intermediate layer of stone masonry, key stones @ at least one stone per 0.5 sqm of plan area or part thereof of layer shall be left projecting upwards in the stone masonry for proper bonding between layers. Wherever the Retaining/ Breast walls are longer than 9m, continuity in length of the Retaining/ Breast wall shall be broken at every 9-10 m or as per the structural design criteria whichever is minimum.

(d) The base width of the walls must be substantial and capable of distributing the pressure over the foundation. The projections of any footing course should not exceed half the depth of the course. The top thickness is usually 0.60 m. The front batter is given as 1 in 3 up to 4 m height and thereafter made flatter and the back face is kept vertical.

(e) Walls should be made in rubble masonry consisting of hammer dressed hard stones brought to course every 0.6 m (approx.). Masonry courses must be normal to face batter; and the back of the wall can be left rough. Masonry work should proceed in a uniform level.

(f) The least dimension of stone should be 20 x 15 x 10 cm. Approximately half the stones should tail into the wall by twice their height. Stones must break joint by half the height of the course.

(g) In case of dry rubber walls, It Is generally advisable to bed each course in stone dust or earth, to spread the load and increase the frictional resistance between courses.

(h) Coping: The coping should consist of large stones, laid and pointed in cement mortar or PCC 50-75 mm thick. The top of the coping should be weather sloped towards valley side. Coping, preferably, should be with stones on edge so that these are not easily dislodged. Parapets with weather slope may be provided on retaining walls in lieu of coping.

(i) Backfill: The backfill layer immediately behind the wall should consist of hand packed stone or some granular material. Remainder of the backfill should be rammed in 150 mm thick layers sloping towards the back of the wall. The top surface should better be sealed with bituminous macadamto prevent unnecessary direct seepage of water in the retaining wall increasing thereby the back pressure.

(j) Drainage: Provision must be made to prevent water accumulating behind the wall. Adequate staggered weep-holes not less than 15 cm x 10 cm should be provided at one meter interval both horizontally and vertically. The inlets of all weep-holes should be surrounded by loose stones. In wet situations a continuous loose stone drain should connect the weep-holes. The weep-holes should have a slope of 1 in 10 towards valley side. Weep-holes are not necessary in dry masonry walls due to open joints though it may be better to provide weep-holes.

(k) Foundations: Foundations must be taken deep enough to rest on sound foundation materials which must be safe from scour, frost and surface water. Rock must be cut in level steps or to a downward slope towards the filling. Rock bed slope should be towards the hill and not away. The necessity of filling foundation pits in front of toe of the retaining wall back up to original ground level, to avoid pooling of water leading to toe erosion, is to be considered.

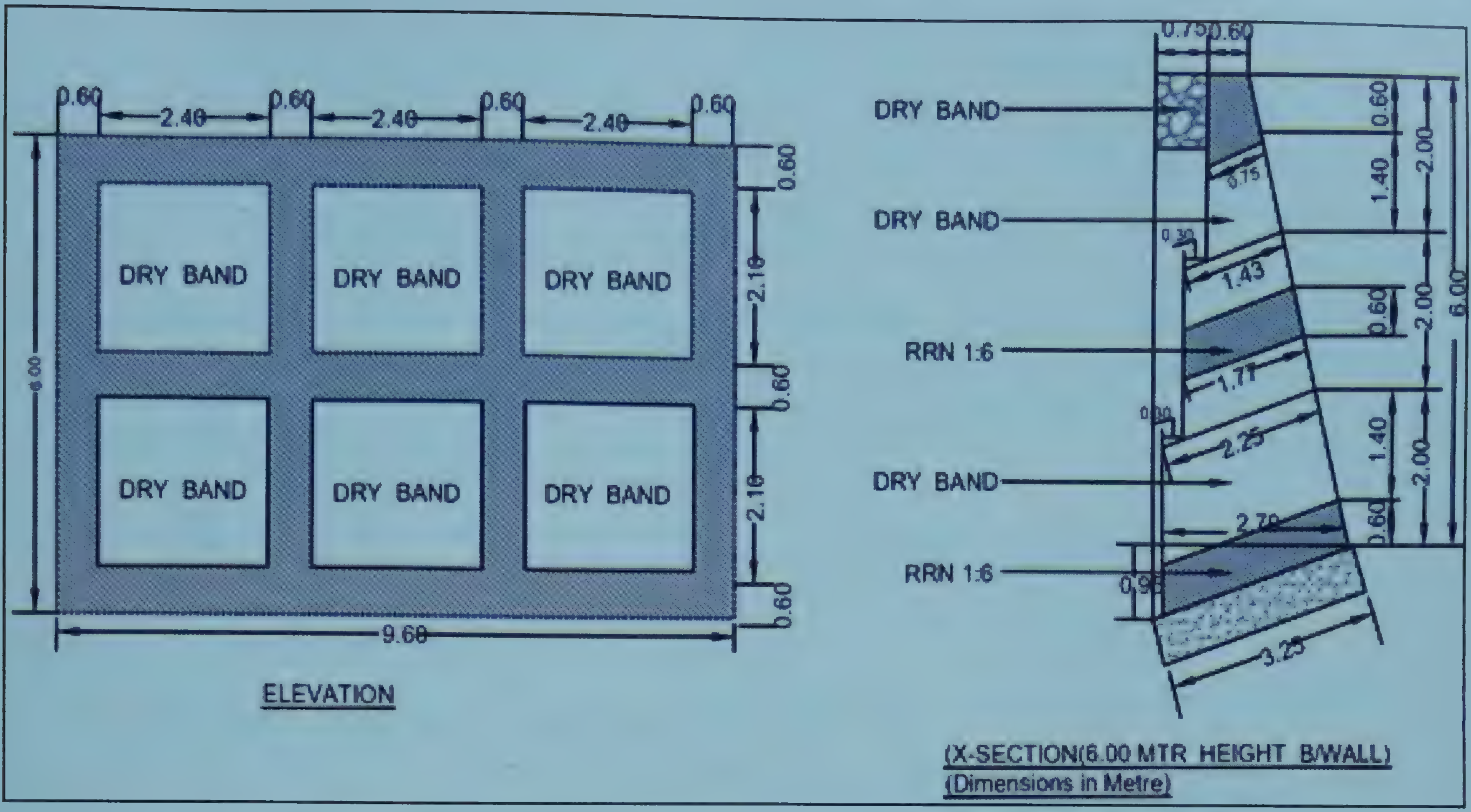

0.60
2.40
0.60
2.40
0.60
2.40
0.60
DRY BAND
DRY BAND
DRY BAND
DRY BAND
DRY BAND
DRY BAND
0.60
2.10
0.60
2.10
0.60
6.00
9.60
ELEVATION
0.75
0.60
DRY BAND
DRY BAND
RRN 1:6
DRY BAND
RRN 1:6
0.75
0.30
1.43
1.77
0.30
2.25
2.70
0.90
3.25
0.60
1.40
0.60
1.40
0.60
2.00
2.00
2.00
6.00
(X-SECTION(6.00 MTR HEIGHT B/WALL)
(Dimensions in Metre)

Fig. 4.15 (A) Typical Section of Banded Dry-stone masonry walls

A2. **Diaphragm Walls** are made of reinforced concrete sections constructed in situ in slots mechanically excavated below the ground surface; their stabilizing action is like that of pile walls, although in contrast to these, diaphragm walls are continuous structures. The diaphragm wall is a structural concrete wall constructed in a deep trench excavation, either cast in situ or using precast concrete components, Diaphragms walls are often used on congested sites, close to existing structures, where there is restricted headroom, or where the excavation is of a depth that would otherwise require the removal of much greater volumes of soil to provide stable battered slopes. For further details on diaphragm walls, reference may be made to IS 9556 "Code of Practice for Design & Construction of Diaphragm walls".

A3. **Crib Walls:** The design of crib walls can be made as per IS 14458: Part-7. Crib walls can be used as restraining structures and may be made of reinforced concrete or steel members. The vertical posts are connected by horizontal members and allow free drainage. These are suitable for small slides that are not deep seated. An arrangement is illustrated in **Fig. 4.16**

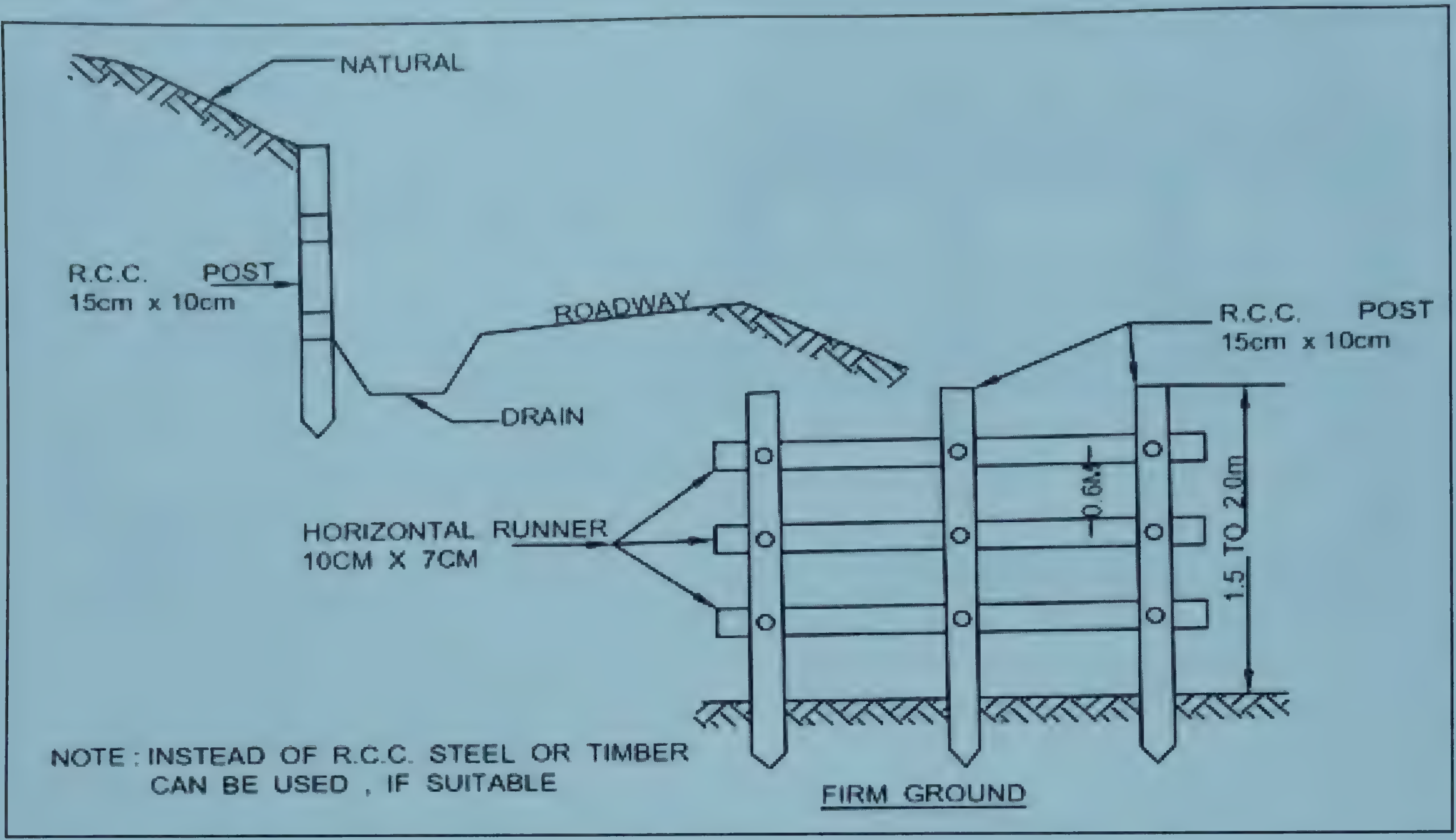

NATURAL
R.C.C. POST
15cm x 10cm
ROADWAY
DRAIN
R.C.C. POST
15cm x 10cm
0.6M
1.5 TO 2.0m
HORIZONTAL RUNNER
10CM X 7CM
NOTE : INSTEAD OF R.C.C. STEEL OR TIMBER
CAN BE USED , IF SUITABLE
FIRM GROUND

Fig. 4.16 RCC Crib Wall

A4. Breast Walls

(i) Masonry or R.C.C. structures supporting the uphill slopes along a road are termed Breast Walls. For protection against instability, slopes of cutting would have to be very flat, which are not economically practicable. At some places such slopes fail by slumping, sliding, toe failures or in the worst cases by failures far below the formation level, causing entire road to be washed away. Thus, weak spots which are chronic by way of hill slides, must be protected by breast walls. Such walls perform the following functions:

(a) They would keep the road edge defined and protect the drain to some extent.

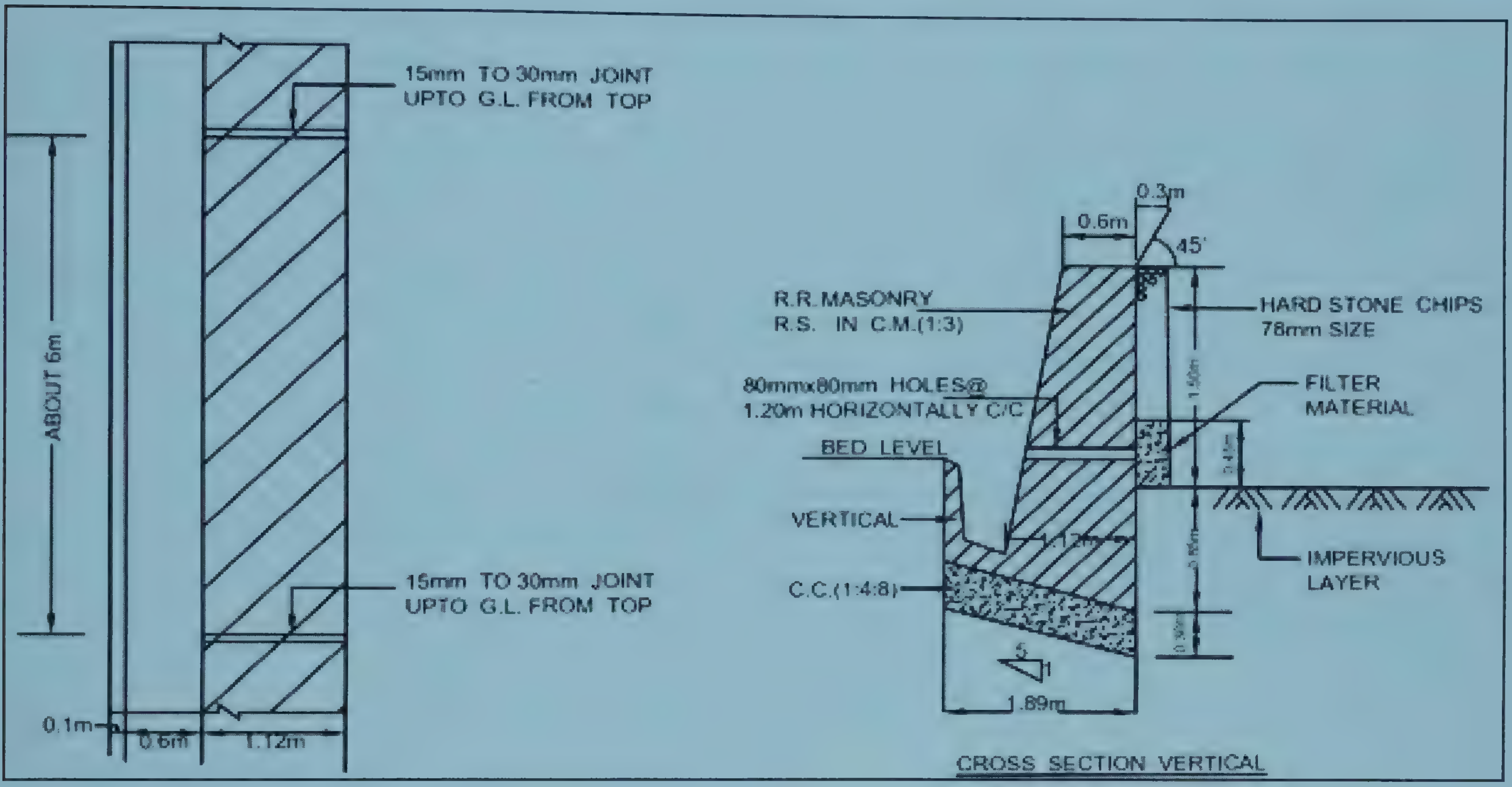
(b) The hill slope to the extent of Breast Wall height will remain protected from slips. Any slide above this height will flow over the top of the breast wall.

(c) It would not allow continuity of the flowing mass of soil and would thus facilitate the clearance of slides

(d) Assistance in drainage from hillslope through weep-holes (Minimum 100 mm diameter with filter or perforated pipe wrapped with non-woven geotextile) in breast wall on to the side drain in front of the wall. IRC:SP:42 shall be referred.

(ii) Materials of construction: Since these walls are usually provided against wet hill slopes, they have to be stronger than Retaining Walls. They are usually provided in stone masonry in cement mortar through bands and dry masonry construction may be done where hillslope is not wet. Weep-holes have to be provided liberally in breast walls. In very unstable situations, gabions have been successfully tried which have the advantage of re-building in case of failure and act as flexible structures. The material specifications of gabions shall meet the requirements given in IS 16014 and MoRTH 2500.

(iii) Design: The breast walls shall be designed as per IS 14458 part -2 "Design of Retaining/Breast Walls". A typical breast wall is given in **Fig. 4.17**.


15mm TO 30mm JOINT
UPTO G.L. FROM TOP
ABOUT 6m
15mm TO 30mm JOINT
UPTO G.L. FROM TOP
0.1m
0.6m
1.12m
0.3m
0.6m
45°
R.R. MASONRY
R.S. IN C.M.(1:3)
HARD STONE CHIPS
78mm SIZE
80mmx80mm HOLES@
1.20m HORIZONTALLY C/C
FILTER
MATERIAL
1.50m
0.45m
BED LEVEL
VERTICAL
1.12m
0.85m
IMPERVIOUS
LAYER
C.C.(1:4:8)
0.30m
5
1
1.89m
CROSS SECTION VERTICAL

Plan
(At Ground Level)

STANDARD 1.50m HIGH BREAST WALL

Fig. 4.17 Typical Section of Breast Wall

Note: *Applicable for only1.5m high breast wall. However, for higher height, it shall be designed as per IS 14458 Part-2 "Design of Retaining/Breast Walls".*

B. Flexible Gravity Retaining Walls

i. Reinforced Soil walls/Slopes: wherein soil/earth is reinforced by metal strips, plastic/polymer strips/grids soil nails to allow the outer face to stand at relatively steep slopes and provide internal stability (Reinforced Soil walls in fly over approaches, soil nailed hill slopes etc.). (Detailed Description is mentioned below)

ii. Shored Mechanically Stabilized Earth (SMSE) Walls/Slopes: wherein combination of in-situ soil nails/ground anchors and reinforced soil wall or slope is used to construct a retaining structure, where existing cut slope is stabilized using in-situ soil nails / anchors and then retaining structure is built by back filling with reinforced soil structure)(Detailed Description is mentioned below)

B1. Gabion Gravity Retaining Walls: -

They are made by forming multi-celled, rectangular mechanically woven steel wire mesh boxes, uniformly partitioned into internal cells, interconnected with other similar units, filled with rock/ boulder or other suitable materials at the project site to form flexible, permeable and monolithic structures. The process is carried out in-situ i.e. at the location where the gabion walls are to be installed on the slide. Over the past 25 years, gabion walls have been used extensively on the Himalayan slopes. Unlike walls made of stone masonry reinforced concrete, the gabion walls have the advantage of being able to withstand large deformations without cracking and are flexible. Further, because of the open structure they allow free drainage of water. These structures blend with the surroundings and allow vegetation to take roots through the structure which enhances the life of the structure. For material specifications and testing of gabions, reference shall be made to IS 16014 and MoRTH 2500 and for design principles and installation methodology of gabion retaining walls, reference shall be made to IRC:SP:116.

Apart from using full height gabion walls or facia system for reinforced soil structures, gabion gravity systems shall be used as toe walls, breast walls and check walls. A row of gabion wall may be placed at the toe of the slide so that serve to improve the stability of the slopes by their dead weight. It is a common practice to use gabion walls to serve as breast walls as well as in the middle of running slopes where they serve as check-walls. In such applications, gabion walls help to retard the flow of water and reduce the surface erosion of the slope, to a certain extent. **Fig. 4.18** illustrates an indicative sketch of gabion retaining wall adopted for road retention purpose. In order to prevent the ingress of soil particles into the voids of a gabion wall, a nonwoven geotextile, filter type 3 or 2 as per IRC:SP:59 shall be provided between gabion and back fill.

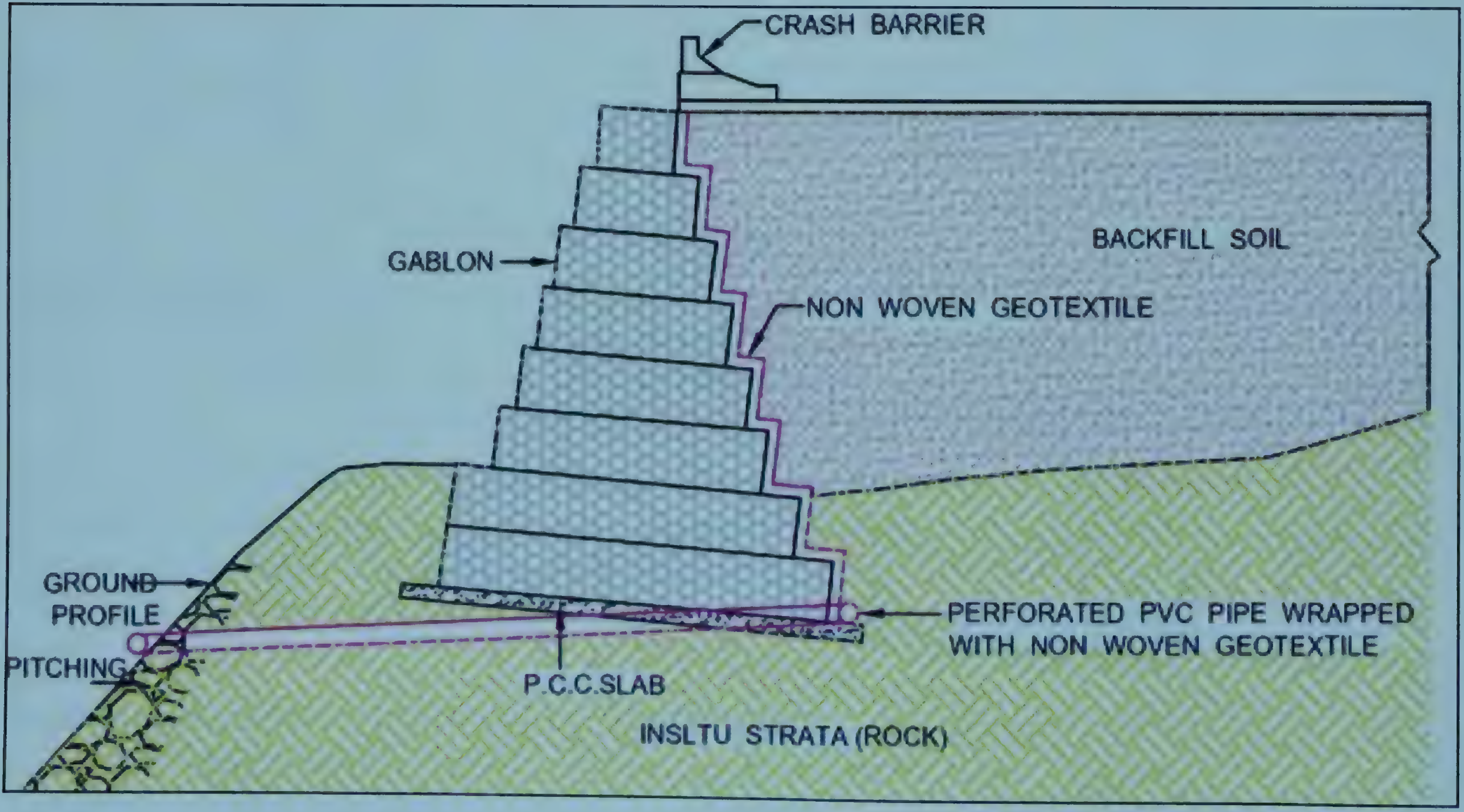


Fig. 4.18 Indicative Cross Section of Gabion Retaining Wall

B2. Reinforced Soil Structures

(i) The concept of reinforced soil has been developed and propagated by Vidal (1966). Reinforced soil walls and reinforced soil slopes are the two major classifications of the reinforced soil system. Reinforced soil structures that are within 20° of the vertical shall be categorized as reinforced soil walls and reinforced soil structures that are $\geq 20^0$ to vertical shall be categorized as reinforced soil slope. Reference shall be made to MoRTH section 3100 for detail specification. As in the case of any gravity structure the internal as well as external stability must be ensured by proper analysis and design, of reinforced soil system.

(ii) Steep slopes require a suitable facing to hold the reinforcement in-place as well as to protect the slope from local instability and erosion adjacent to the face. In the case of flatter slopes also, facing may be called for. Depending upon the properties of the fill and local climatic conditions of the area, suitable slope protection measures need to be adopted. The generally used facia types include wrap around facing, precast reinforced concrete panels etc. as described in MoRTH 3100.

(iii) Reinforced soil fills require granular type of fill material since good frictional resistance is required for developing the reinforcing effect. **Fig. 4.19,** shows the use of reinforced soil system for controlling and improving the stability of the earth fill slopes. For design and analysis of reinforced soil structures, reference shall be made to IRC SP 102, BS 8006 Part-1, FHWANHI 10-024& 025, AASHTO.

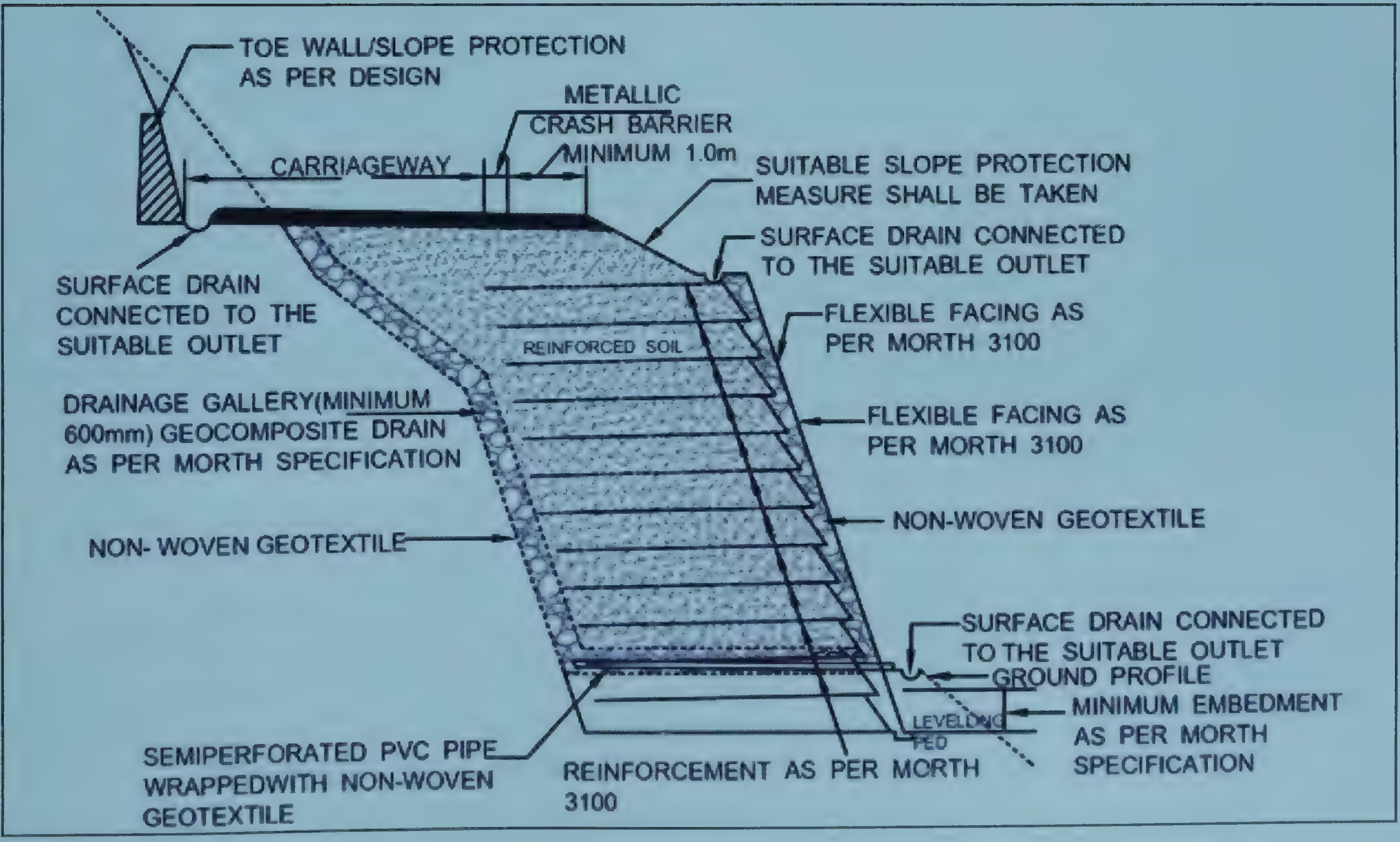

TOE WALL/SLOPE PROTECTION AS PER DESIGN
METALLIC CRASH BARRIER
CARRIAGEWAY
MINIMUM 1.0m
SUITABLE SLOPE PROTECTION MEASURE SHALL BE TAKEN
SURFACE DRAIN CONNECTED TO THE SUITABLE OUTLET
SURFACE DRAIN CONNECTED TO THE SUITABLE OUTLET
FLEXIBLE FACING AS PER MORTH 3100
REINFORCED SOIL
DRAINAGE GALLERY(MINIMUM 600mm) GEOCOMPOSITE DRAIN AS PER MORTH SPECIFICATION
FLEXIBLE FACING AS PER MORTH 3100
NON-WOVEN GEOTEXTILE
NON- WOVEN GEOTEXTILE
SURFACE DRAIN CONNECTED TO THE SUITABLE OUTLET
GROUND PROFILE
MINIMUM EMBEDMENT AS PER MORTH SPECIFICATION
LEVELLING PED
SEMIPERFORATED PVC PIPE WRAPPEDWITH NON-WOVEN GEOTEXTILE
REINFORCEMENT AS PER MORTH 3100

Fig. 4.19 Typical Cross Section of Reinforced Soil Slope with either Stone (Mineral) or Green Finish Flexible Facing

(iv) Reinforced soil walls have been constructed from as early as 1974 in many countries. The alternative would have been the construction of high retaining structures or viaducts which are costlier. The general behavior of reinforced soil walls was found to be satisfactory, even under conditions where the hill slopes experienced movements. This is attributed to the good deformability of reinforced soil structures. In such situations rigid structures would suffer damages. In addition to the flexibility of reinforced soil structures in design and construction, seismic testing conducted on a large scale shaking table laboratory at the Japan National Institute of Agricultural Engineering (Tsukuba City), showed that reinforced walls, retain sufficient flexibility to withstand large deformations without loss of structural integrity, and have high seismic load resistance. However, the external/internal checks, connection system between the soil reinforcement and the facing, global stability checks shall be designed as per relevant design codes. Reference shall be made to Section 3100 of MORTH Specification, IRC:SP:102, BS 8006 / FHWA-NHI-10-024 / FHWA-NHI-10-025 for design of slopes and walls.

B3. Shored/Hybrid Reinforced Soil Structures

(i) Shored reinforced soil structure is a combination of in-situ soil nailed slope and reinforced soil structure as shown in **Fig. 4.20.** The reinforced soil wall/slope is constructed by connecting the reinforcement with the soil nailed structure. This solution is suitable when the required base width is not available for design of any conventional retaining structure.

(ii) The design concept of shored reinforced soil system is to reinforce and strengthen the unstable cut slopes by in-situ installation of hot dip galvanized soil nail/anchors and connecting the nails/anchors with reinforced soil structure system to transfer the load from build-up reinforced soil mass to in-situ soil nails. The recommendations on FHWA guideline (FHWA-CFL/TD-06-001) are based on the results of the modeling and field-testing research. The design guideline recommends a minimum base reinforcement length equivalent to as little as 30 percent of the wall height (0.3H) for the MSE wall component and provided that the MSE reinforcement length is greater than 1.5 m (whichever is greater).

- **Connection System:** The connection between the reinforced soil slope and soil nail and/ or ground anchors can be frictional/ positive/mechanical in nature for full load transfer mechanism as per FHWA-CFL/TD-06-001 when available base width is more than 30% of the height of the structure. However, if adequate base width is not available (base width < 30% of the height of wall/ slope), the backfilled reinforced soil wall shall be mechanically connected with the soil nailed/ ground anchored stabilized slope. The connection between the reinforced soil slope and soil nail and/ or ground anchors shall be mechanical in nature for full load transfer mechanism and having rotational flexibility in both horizontal and vertical plane. All steel components of the connection are hot-dip galvanized confirmed to BS 729:1971 requirements or IS 4759:1996, except that the average zinc coat weight is not less than 500 gm/m2.

- **Soil Nails:** Soil Nail shall be fully threaded solid geotechnical bars which are hot – dip galvanized conforming to IS 4759 requirements, except that the average zinc coating weight on nail surface is not less than 500 gm/m2.
- **Ground Anchors:** Depending on the soil strata, height of the structure and slope stability design, the excavated slope surface might needs to be strengthened by permanent ground anchors for better performance;

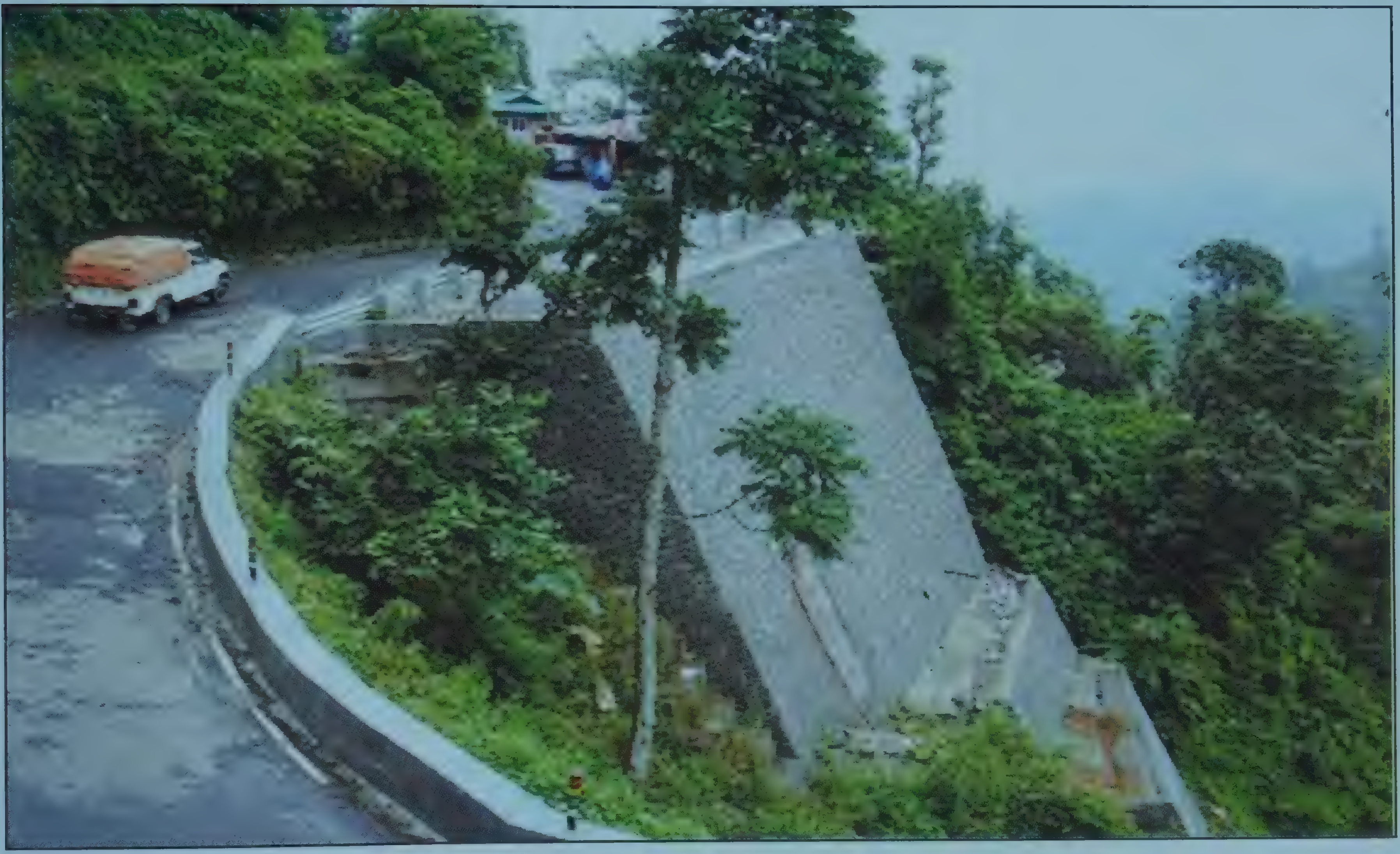


Fig.4.20 Site Photograph of Shored/Hybrid Reinforced Soil Structures

B4. Toe and Check Walls

(i) When culverts/scuppers are constructed and water falls above the retaining walls on the valley side to a considerable height, in the form of a free fall, there is considerable erosion, at the toe of the retaining wall. In order to check this erosion, one or a series of toe walls with Stone pitching flooring/apron between retaining and toe walls and between toe walls are constructed in order to break the water force so that the retaining wall does not get eroded.

(ii) In some cases, similar structures called check walls are required in the nallah bed on the upstream side of the road to reduce the flow of debris which blocks the road.

(iii) Typical sections and arrangement of Toe and Check walls are given in **Fig. 4.21**.

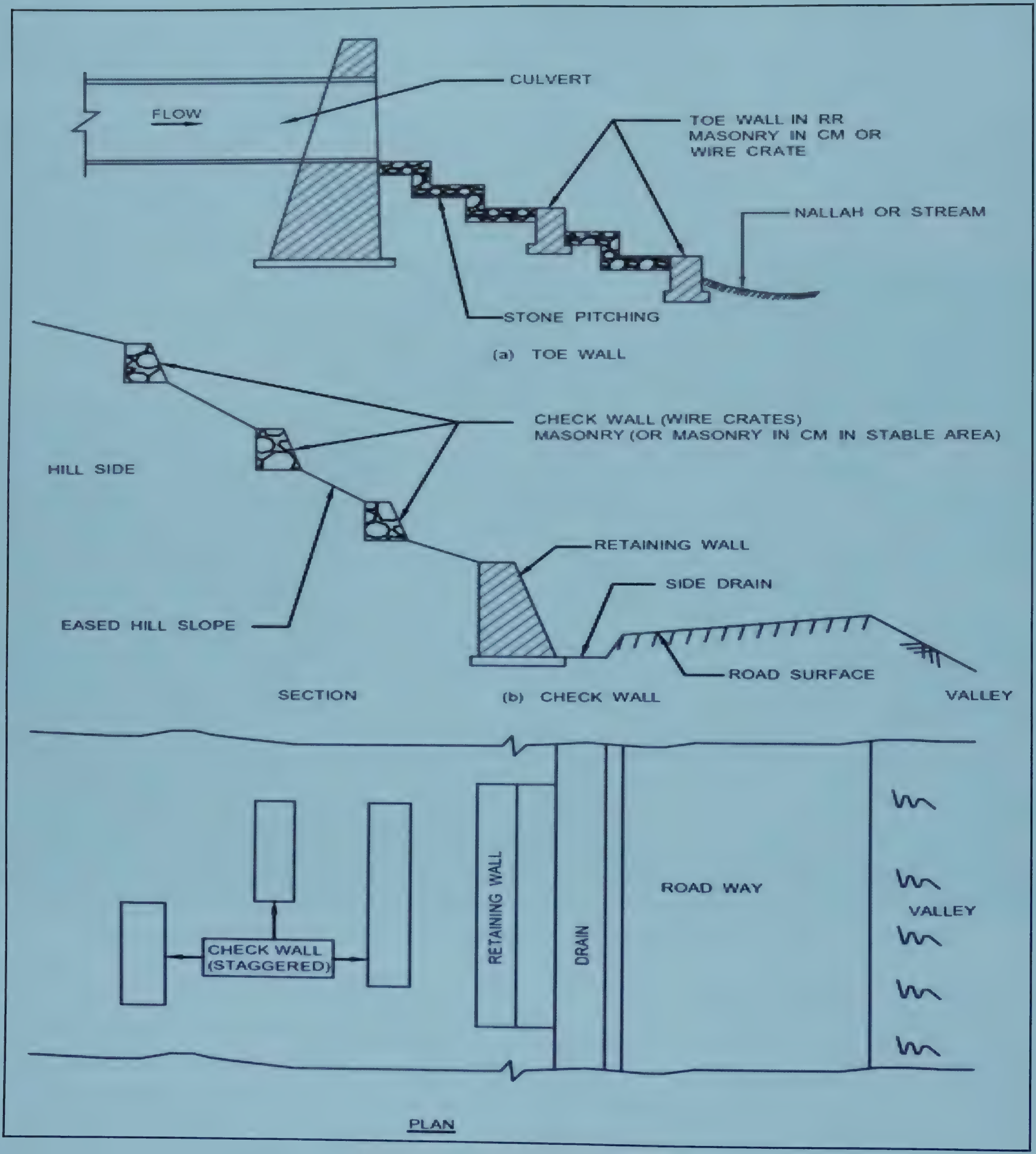

CULVERT
FLOW
TOE WALL IN RR MASONRY IN CM OR WIRE CRATE
NALLAH OR STREAM
STONE PITCHING
(a) TOE WALL
CHECK WALL (WIRE CRATES) MASONRY (OR MASONRY IN CM IN STABLE AREA)
HILL SIDE
RETAINING WALL
SIDE DRAIN
EASED HILL SLOPE
ROAD SURFACE
SECTION
(b) CHECK WALL
VALLEY
RETAINING WALL
DRAIN
ROAD WAY
VALLEY
CHECK WALL (STAGGERED)
PLAN

Fig. 4.21 Toe & Check Walls

B5. River Training Structures

(i) As hill roads, in many cases, are aligned along river courses, river training measures like spurs or groins, slope pitching, aprons etc. are required to be provided at the toe of downhill slope of road to prevent erosion and subsidence of roadbed. The materials used for bank protection along rivers can be flexible structures like riprapping the toe of the slope or provide mechanically woven steel wire mesh gabion boxes/mattresses or it shall be fabric form mattress. However, all river toe protection system in hill roads shall be designed against any possibility of damage that can be caused due to hitting of boulders or debris.

(ii) Designs have to be evolved to suit site conditions as per sound engineering practice in each case. A few typical sections and arrangements are given in **Fig. 4.22**. While designing for a riverbank wall or a revetment or a scour apron, hydraulic stability and environmental stability shall be ensured in addition to geotechnical stability. Mattresses shall be placed on a geo-technically stable slope only after adopting any required geotechnical stabilization measures. Usual procedure for hydraulic stability analysis is to select the thickness of mattress and check the stability against tractive shear forces criteria, velocity criteria and deformation criteria as per IRC:SP:116 and IRC:89. The sizes of stones and specifications of gabions and mattresses shall be as per IS 16014 and MoRTH 2500. The important parameters to be considered for the design are peak velocity of flow, riverbed gradient, peak flood discharge, type of soil on the riverbank and bed, river width, different water levels (i.e. low, normal and high-water levels) and river /channel geometry.

(iii) Toe protection of a slope shall be provided in such a way that it will not slide due to undermining and scouring at the toe. For toe protection, mattresses in the form of launching apron or toe wall shall be provided on the severity of the scour. Launching apron should be laid at low water level **Fig. 4.23 & Fig. 4.24.** The launching apron should be designed to launch along the slope of the scour and provide a protection layer so that scouring is checked. The size of the launching apron should form a protection layer upto a level of maximum scour depth. A non-woven Type 1 geotextile as per IRC:SP:59 shall be adopted as per the selection criteria. Wherever the slope protection or riverbank walls are subjected to stone hitting, that shall be taken care by providing strong material which can sustain the impact load alternatively, the face shall be grouted.

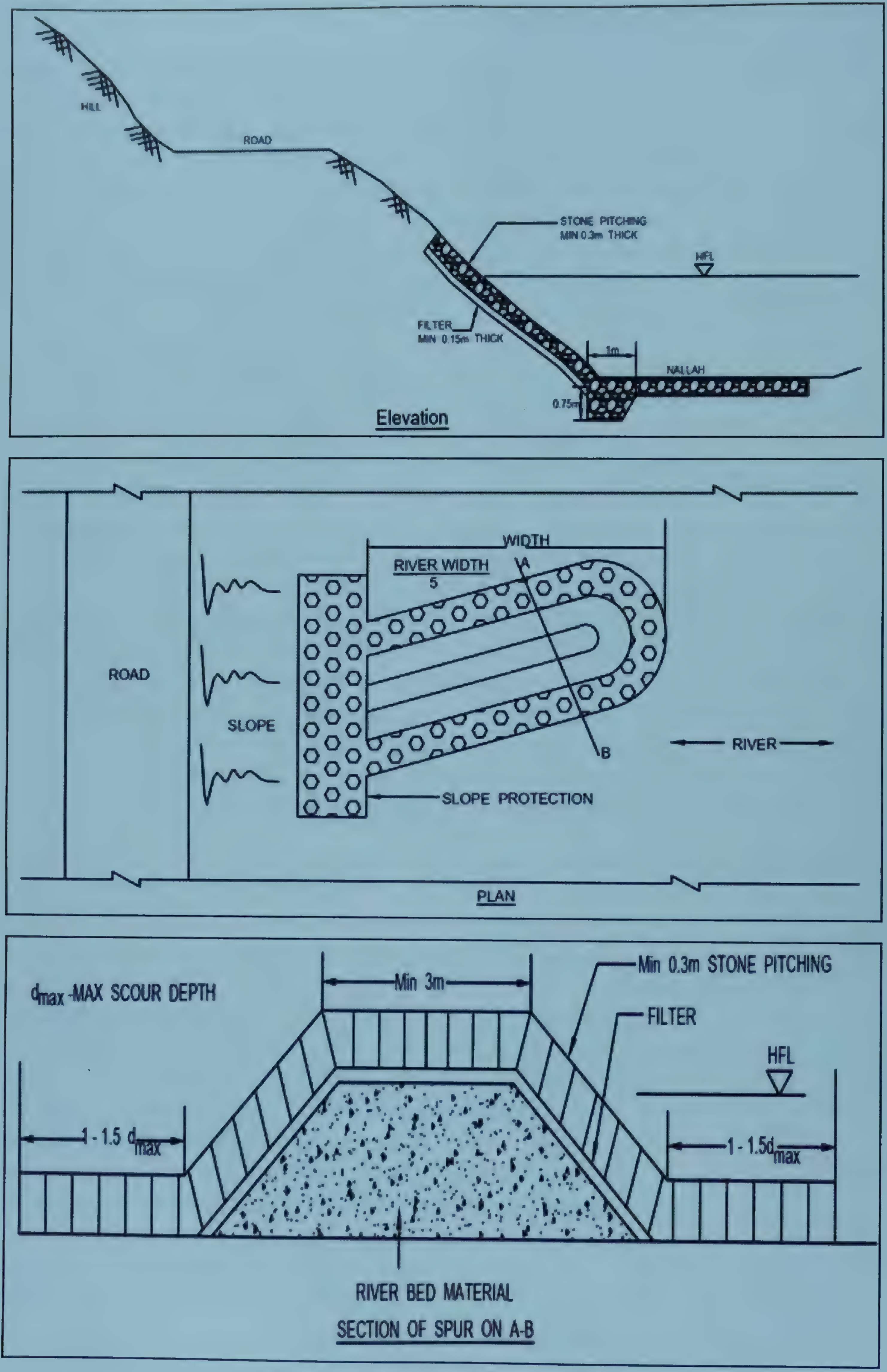

HILL
ROAD
STONE PITCHING
MIN 0.3m THICK
HFL
FILTER
MIN 0.15m THICK
1m
NALLAH
0.75m
Elevation
WIDTH
A
RIVER WIDTH
5
ROAD
SLOPE
B
RIVER
SLOPE PROTECTION
PLAN
d_{max} -MAX SCOUR DEPTH
Min 3m
Min 0.3m STONE PITCHING
FILTER
HFL
1 - 1.5 d_{max}
1 - 1.5d_{max}
RIVER BED MATERIAL
SECTION OF SPUR ON A-B

Fig. 4.22 River Training Works

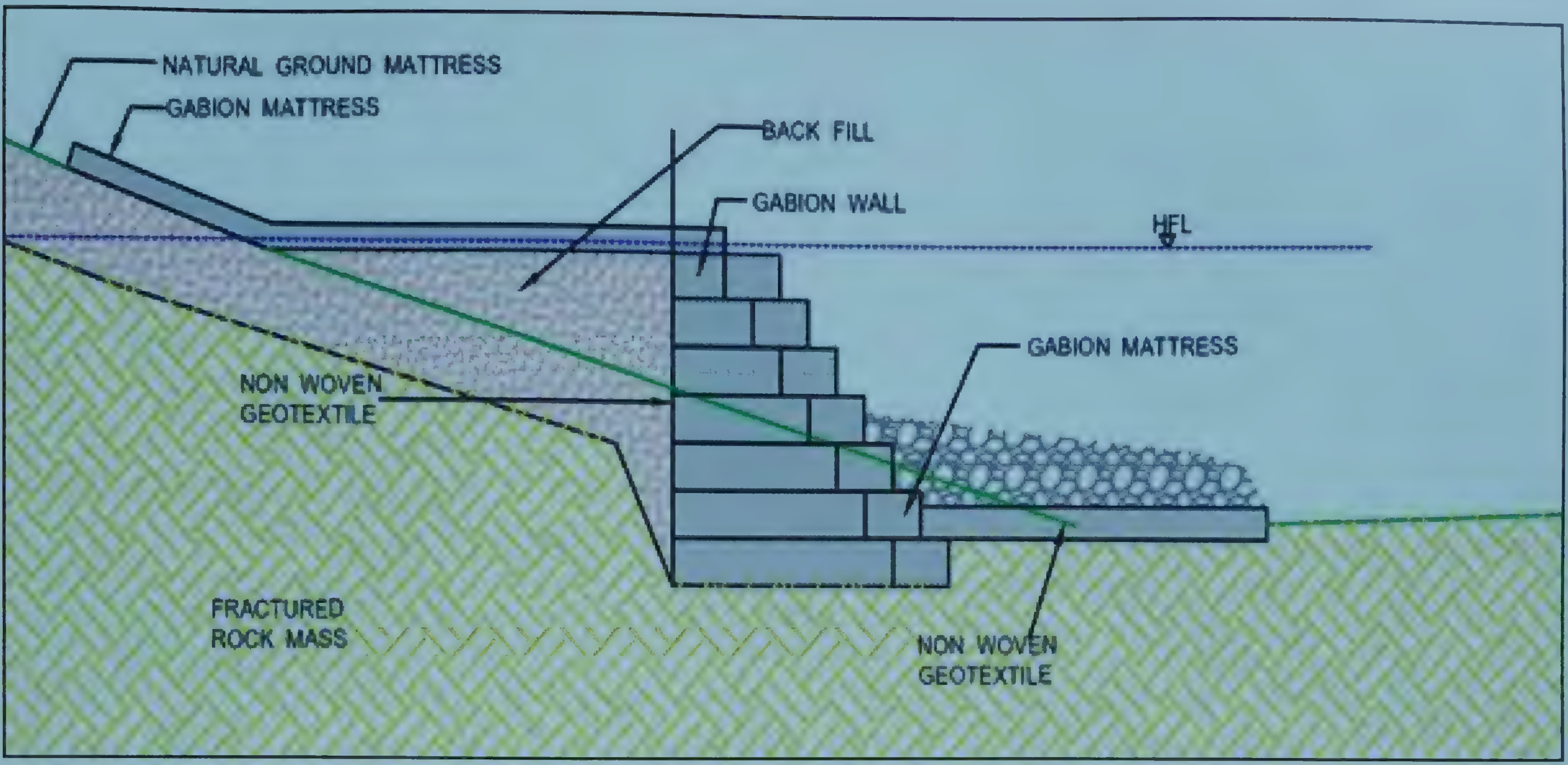

NATURAL GROUND MATTRESS
GABION MATTRESS
BACK FILL
GABION WALL
HFL
GABION MATTRESS
NON WOVEN GEOTEXTILE
FRACTURED ROCK MASS
NON WOVEN GEOTEXTILE

Fig. 4.23 Typical Cross Section of Gabion Retaining Wall with Launching Apron on a River Stream Bed

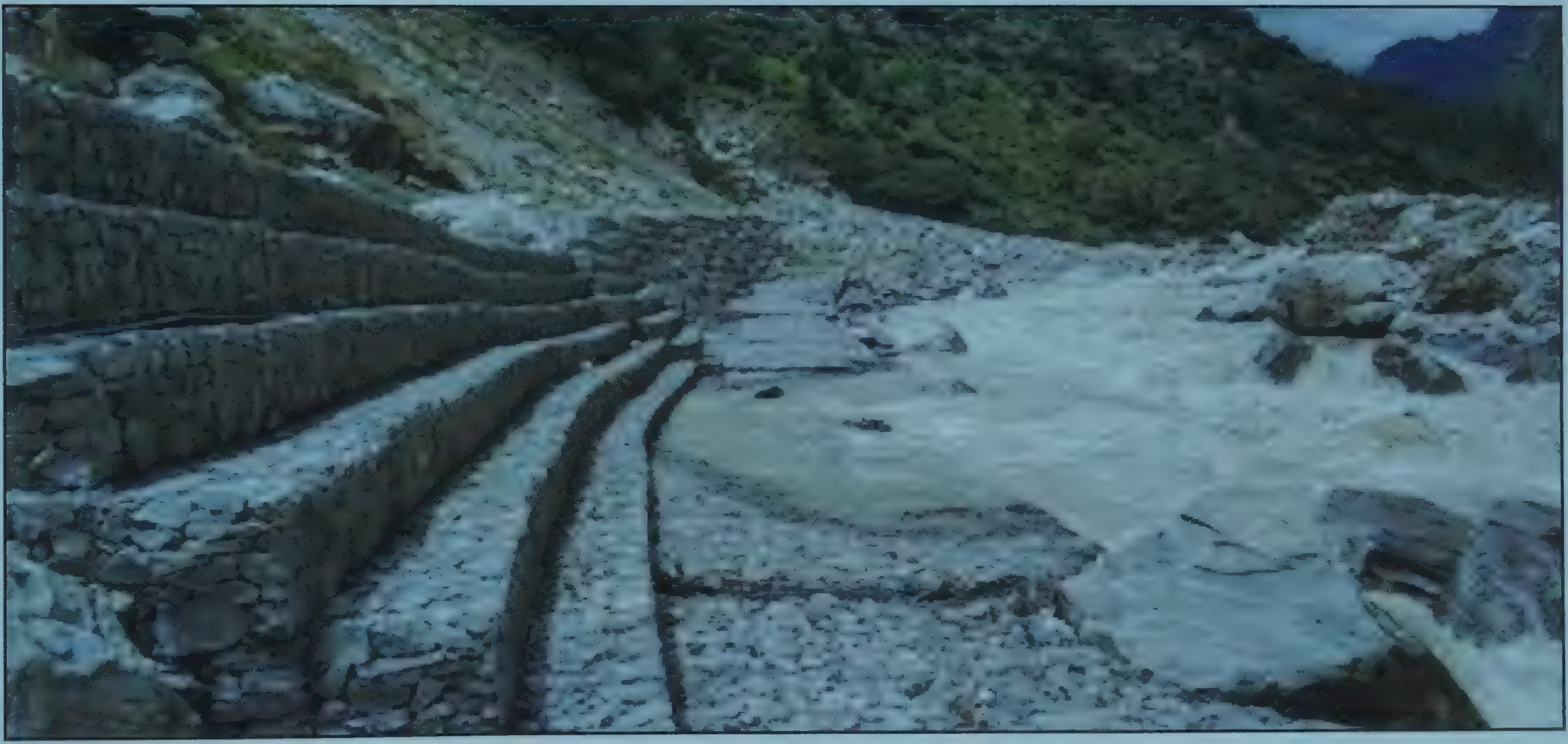
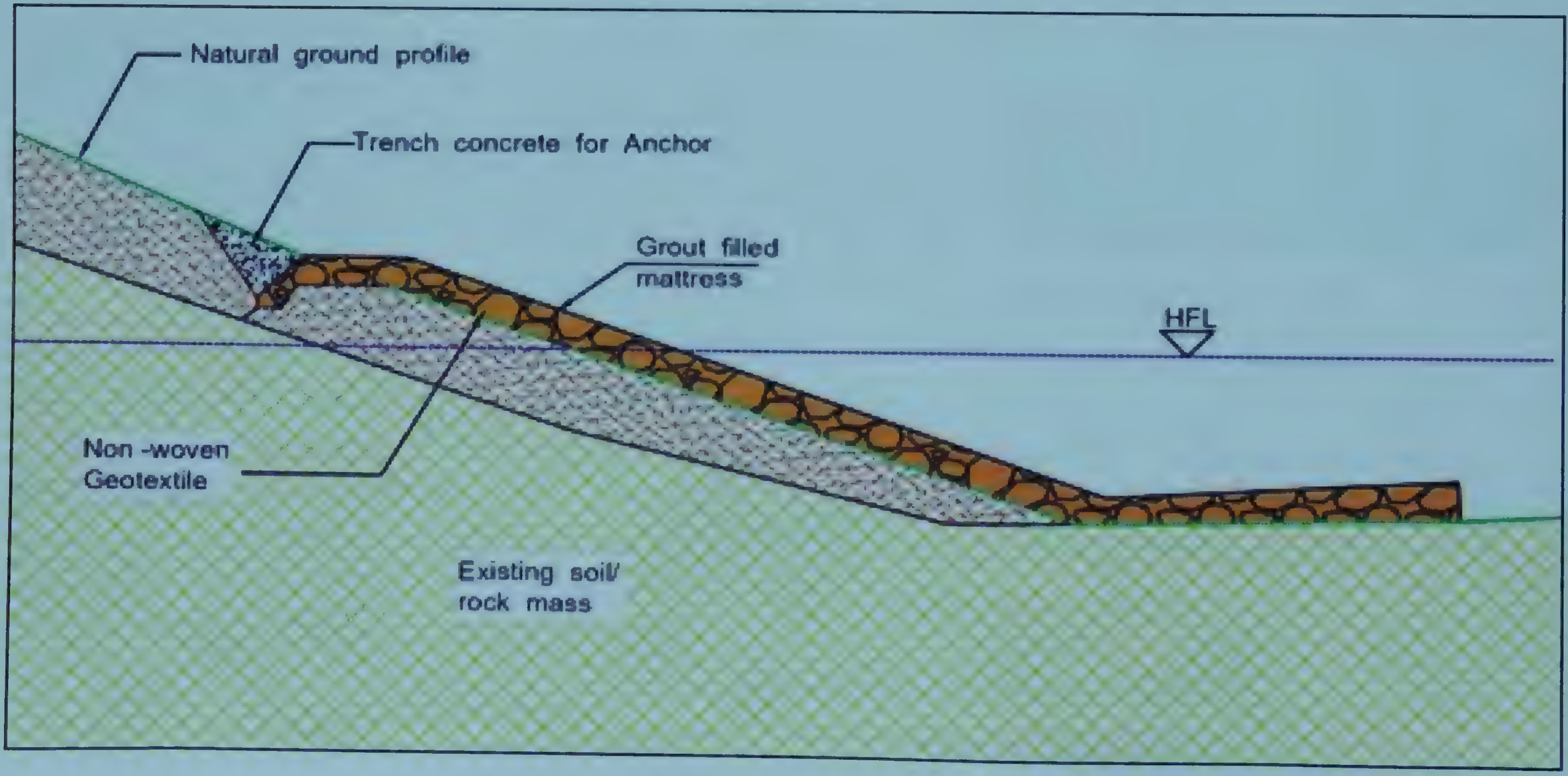


Fig. 4.24 Site Photograph of Gabion Retaining Wall with Launching Apron on a River Stream Bed

(a) Fabric form erosion and scour protection concrete mattress is an alternative solution for erosion control protection, scour protection, canal lining, beautifications of riverbank or lake bund. The grout filled mattress system comprises of a double layer of strong synthetic fabric sewn into a series of pillow-shaped components that are connected internally by ducts and filled with a concrete grout that flows form compartment to compartment via the ducts **(Fig. 4.25)**. The fabric mattress shall be fabricated at a factory as per site geometry and supplied at site. This process improves the quality and speed of installation. The grout filled mattress is installed on the banks of the water body or any other embankment to prevent the soil or sand erosion from slope. These mats are typically sewn together or otherwise connected (less commonly) by special zips, straps, or ties prior to filling. When set the grout form a mat made up of a grid of interconnected blocks. Fabric form mats are reinforced by cables laced through the mat before the concrete is pumped into the fabric form, creating what is called an Articulating Block Mat (ABM). This mattress with cable is recommended at apron location to facilitate launching during scouring. Depending on the criticality of the condition, the mattress type (with cable or without cable) shall be decided. Flexibility and permeability are important functions for stream instability and scour countermeasures. Therefore, systems that incorporate filter points or weep holes (allowing for pressure relief across the mat) combined with relatively small-diameter ducts (to allow breakage and articulation between the grout blocks) are the preferred products.

(b) The selection of the fabric form primarily depends on the technical requirements. Hydraulic design is carried out based on the flow velocity, wind velocity, scour depth, slope of the bank and bed, purpose of the project etc. For the specifications of materials i.e. geotextile form, cables, grout and grout filled mat, quality criteria, design and installation, reference shall be made to FHWA -NHI-09-112 (HEC 23). A non-woven Type 1 geotextile as per IRC:SP:59 shall be adopted as per the selection criteria shall be placed behind the revetment lining.

(c) This solution is environmentally sustainable with limited use of equipment and machineries at site. The installation can also be done very fast at site and pre-engineered for high quality standard. Hence, the mattress shall be customized as per site geometry or profile at factory in the form of panels along with geotextile baffles and one panel shall be connected with the adjacent panel by using Industrial Zipper.



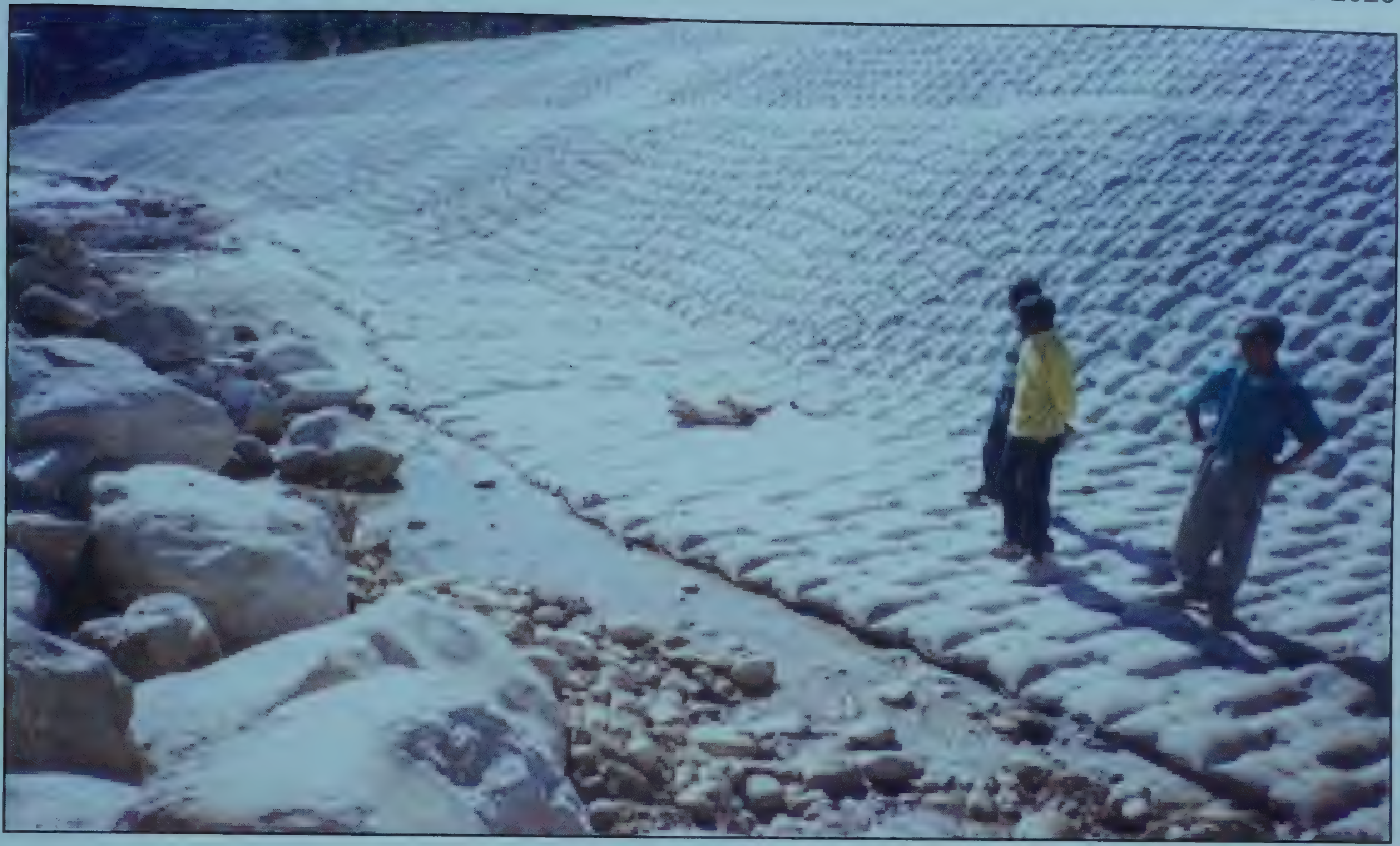


Fig. 4.25 Typical Cross Section and Site Photograph of Fabric Form Mattress with Launching Apron on a River Stream Bed

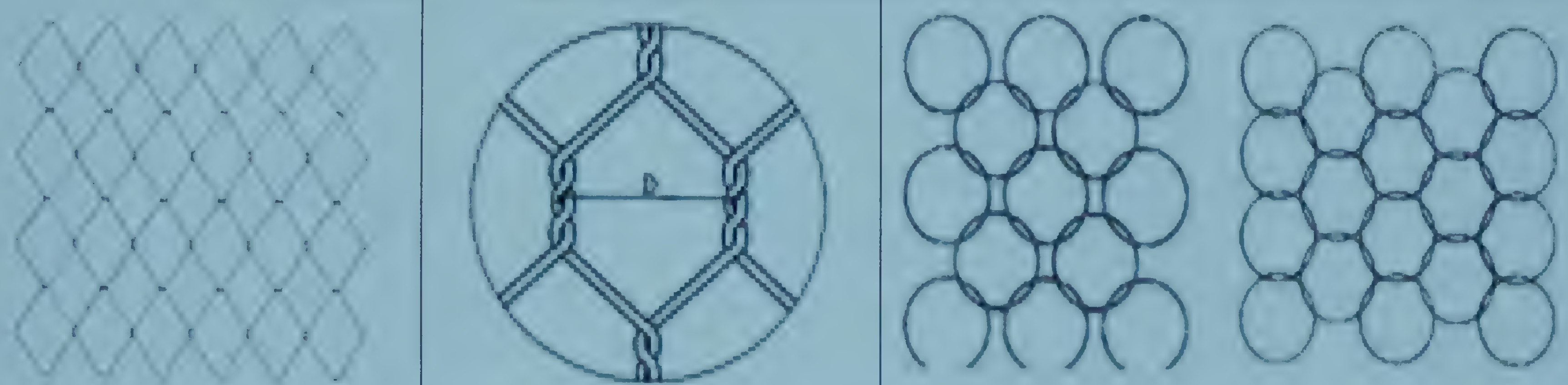
B6. Soil Nailing/Rock Bolting (Passive system)

(i) Soil nailing is a technique in which unstable natural soil slopes, excavations or retaining walls are passively reinforced by the insertion of relatively slender elements – normally steel reinforcing bars that allows the safe over steepening of new or existing soil slopes. Such a structural element which provides load transfer to the ground in excavation reinforcement application is called nail. Solid bars are usually installed into pre-drilled holes and then set in place using grout with a separate grout line, whereas hollow bars may be drilled and grouted simultaneously by the use of a sacrificial drill bit and by pumping grout down the hollow bar as drilling progresses. Soil nails are usually installed at an inclination of 10 to 20 degrees with horizontal and are primarily subjected to tensile stress. In this technique, tensile stress is applied passively to the nails in response to the deformation of the retained materials during the subsequent excavation process. Soil nailing is typically used to stabilize unstable natural soil slopes, existing slopes or excavations where top-to-bottom construction is advantageous compared to the other retaining wall systems.

(ii) Generally, soil nail installation techniques in practice are: (i) drilled and grouted soil nails, (ii) self-drilled soil nails and (iii) driven soil nails. Grouted nails are recommended for all types of soil nail walls applications, and in particular, for walls with vertical height more than 7 m. Driven nails shall only be used when wall heights are smaller (less than or up to 7 m). The major difference between the two is the pullout resistance of the soil nails and grouted soil nails are expected to have higher pull-out resistance compared to driven nails. Pull-out test is desirable to check the values of pullout resistance which is useful in soil nail design. Self-drilled soil nails are applicable for weak strata which are collapsible during the nailing operations. In the case of self-drilled soil nails, grouting shall be carried out simultaneously through the hollow drill bar during the drilling operation. Along with the nails, facia shall be provided to stabilize the surface. It provides lateral confinement for the retained soil between the nail head locations. Progressive shallow failure will occur if the facing does not stabilize the surface of the ground between the soil nails. For further details reference may be made to MoRTH 3200 & FHWA-NHI-14-007.

B7. Secured Drapery System (Passive system):

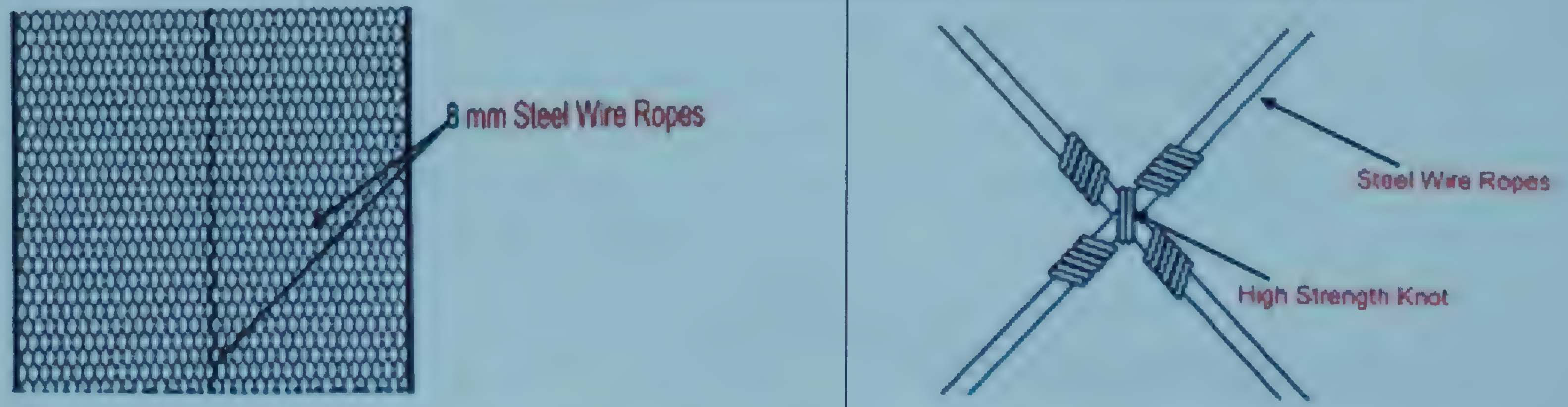
(i) Drapery systems will be a significant component of most of the protection, retention and prevention systems. Many times, their function will be to act as facia systems where prevention or retention is mainly done through long nails/anchors/bolts or surfaced nails/anchors/bolts. A typical example showing different types of products and their specification standards are given in **Fig. 4.26**



(a) Single twist mesh as per WSDOT manual

(b) Simple rockfall netting as per IS 16014

(c) Typical ring net layout with 4 point and 6-point connection as per ISO 17745



(d) Mono-oriented reinforced mesh as per WSDOT manual

(e) Cable panels with a knot as per ISO 17746

Fig. 4.26 Typical Example of Different Types of Drapery Systems used for Rock fall Mitigation Measures

The main purpose of Secured Drapery system is to stabilise the superficial portion of the rock by nails and keep in place the unstable/loose rock pieces by the mesh. In secured drapery system flexible facing systems are used on the slope and the top loose surface of the rock mass along the length of the slope and strengthened with surface nails, bolts and anchors. The goal of secured drapery systems is to retain rockfalls within the mesh system in cases where no catchment/storage area is available at the base of the slope. Secured draperies typically provide active reinforcement and resistance to the initiation of rockfall events.

The common products used for facia of drapey systems are single twist mesh, simple rockfall netting, ring net with 4 points and 6-point, mono-oriented reinforced mesh,. The standards giving the material specifications are WSDOT manual (for single twist mesh, mono oriented steel reinforced mesh, bi-oriented reinforced mesh), IS 16014 (for simple rockfall netting), ISO 17745 (for ring nets), ISO 17746 (for cable panels with knot and clips). Washington State Department of Transportation manual (WSDOT) provides design guidelines, generalized plans and specifications for slope protection systems that can be applied by a geotechnical specialist to a broad range of field conditions. The standard test methods to evaluate the performance of a different type of mesh system shall be as per IS 16014 or ISO 17745 or ISO 17746 or European Assessment Document – EAD 230025-00-0106.

(ii) Reinforcing rock slope by anchors/bolts/nails for prevention of rock falls with a suitable drapey system as facia. Anchor/bolts/nails are tools composed of steel rods/tendons/cable anchors that reinforce and tie together a rock/soil boulder mix face to improve its stability (**Fig. 4.27**). Anchors are active or passive members used to support large blocks of rock, whereas bolts are shorter and support surface rock. Dowels are similar to bolts but are not post-tensioned. Reinforcing a rock slope with anchors/bolts/nails requires a specialist’s knowledge of rock stability analysis of grouting techniques and testing procedures. The determination of the orientation of the potential failure surfaces is crucial to a successful anchor system and requires a considerable amount of engineering experience. For definitions, materials, applications, feasibility evaluations, mechanism, design, construction steps, performance monitoring, corrosion protection etc. for soil nailed walls/anchored walls, reference shall be made to FHWA-NHI-14-007 (soil nailing), BS: 8006 Part-2 (soil nailing), FHWA-IF-099-015 (ground anchors) and BS 8081 (ground anchors).

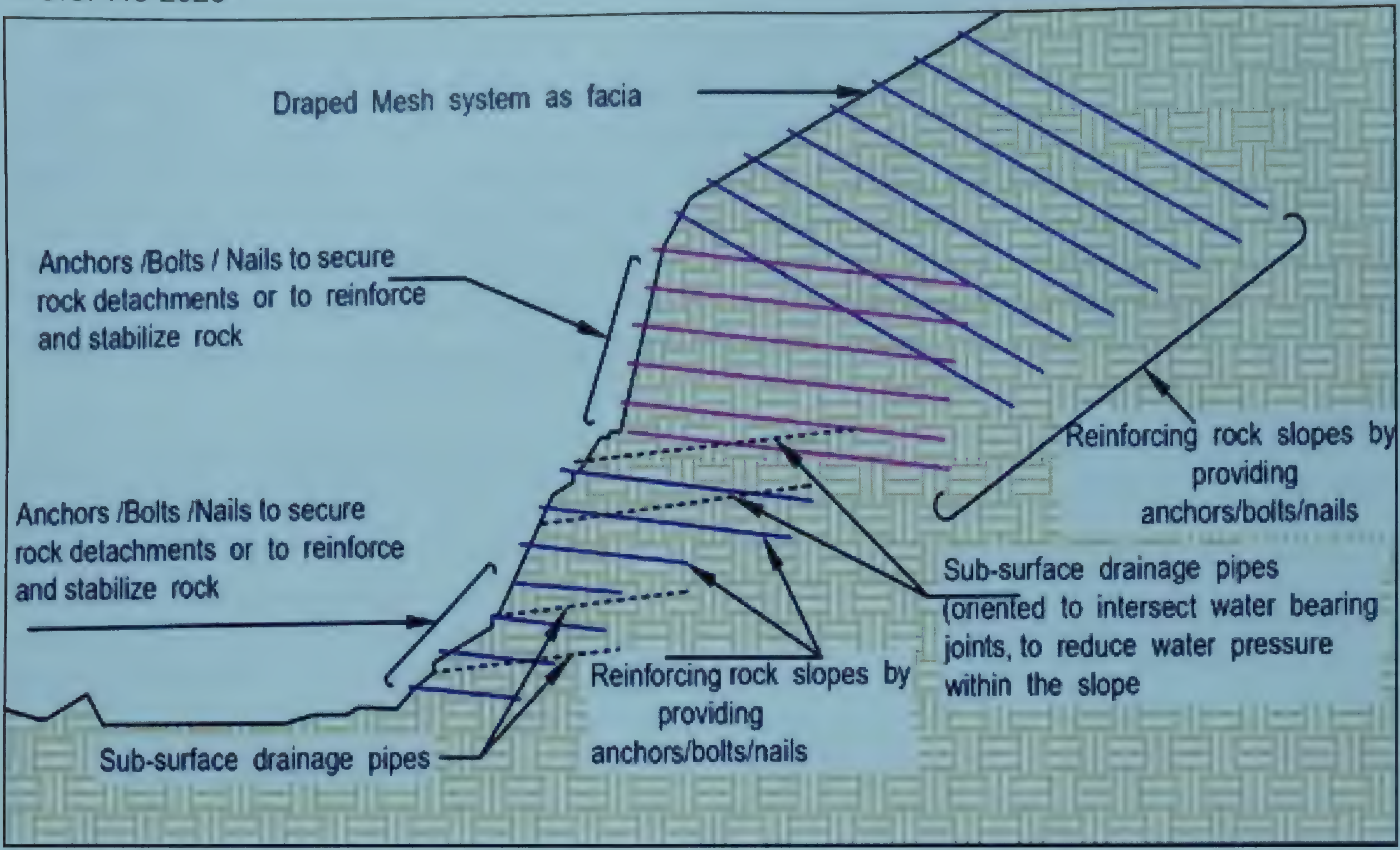

Draped Mesh system as facia
Anchors /Bolts / Nails to secure rock detachments or to reinforce and stabilize rock
Anchors /Bolts /Nails to secure rock detachments or to reinforce and stabilize rock
Reinforcing rock slopes by providing anchors/bolts/nails
Sub-surface drainage pipes (oriented to intersect water bearing joints, to reduce water pressure within the slope
Reinforcing rock slopes by providing anchors/bolts/nails
Sub-surface drainage pipes

Fig. 4.27 Typical Cross-Section of Reinforcing Rock Slope by Anchors/Bolts/Nails

(iii) Shotcreting and Grouting

Shotcrete can be defined as mortar or concrete conveyed through a hose and pneumatically projected at high velocity on to a surface. The force of the jet impinging on the surface compacts the material. Shotcrete and grout the type of concrete is applied by air-jet directly onto the surface of an unstable rock face. Shotcrete is an all-inclusive term to describe the spraying of concrete or mortar either by a dry- or a wet-mix process. This is a rapid and relatively uncomplicated method commonly used to provide surface reinforcement between blocks of rock and also to reduce weathering and surface scaling. Shotcrete contains aggregate up to 20 mm in size and layer thickness varies from 70 mm to 100 mm. Before shotcrete, the surface should be thoroughly scaled of loose rock pieces. Sometimes, a steel wire mesh is bolted to the slope face before shotcreting is done. It is desirable to insert pipes into the soil-rock slope to provide drainage and avoiding built of pore water pressure after shotcreting is done on the slope. **Fig. 4.28** shows the work of shotcreting in progress IS 9012 can be referred for shotcreting application. Grouting is used to improve weathered slopes from which rock or boulders may be falling. The proper type of grout and safe injection pressure has to be determined carefully. Stringent quality control has to be exercised on mix proportions, water content and grout pressure etc. during grouting operation. IS code is available for shotcrete gradation and construction methodology. For further details for shotcreting and grouting, reference may be made on FHWA-CFL/TD-11-002.

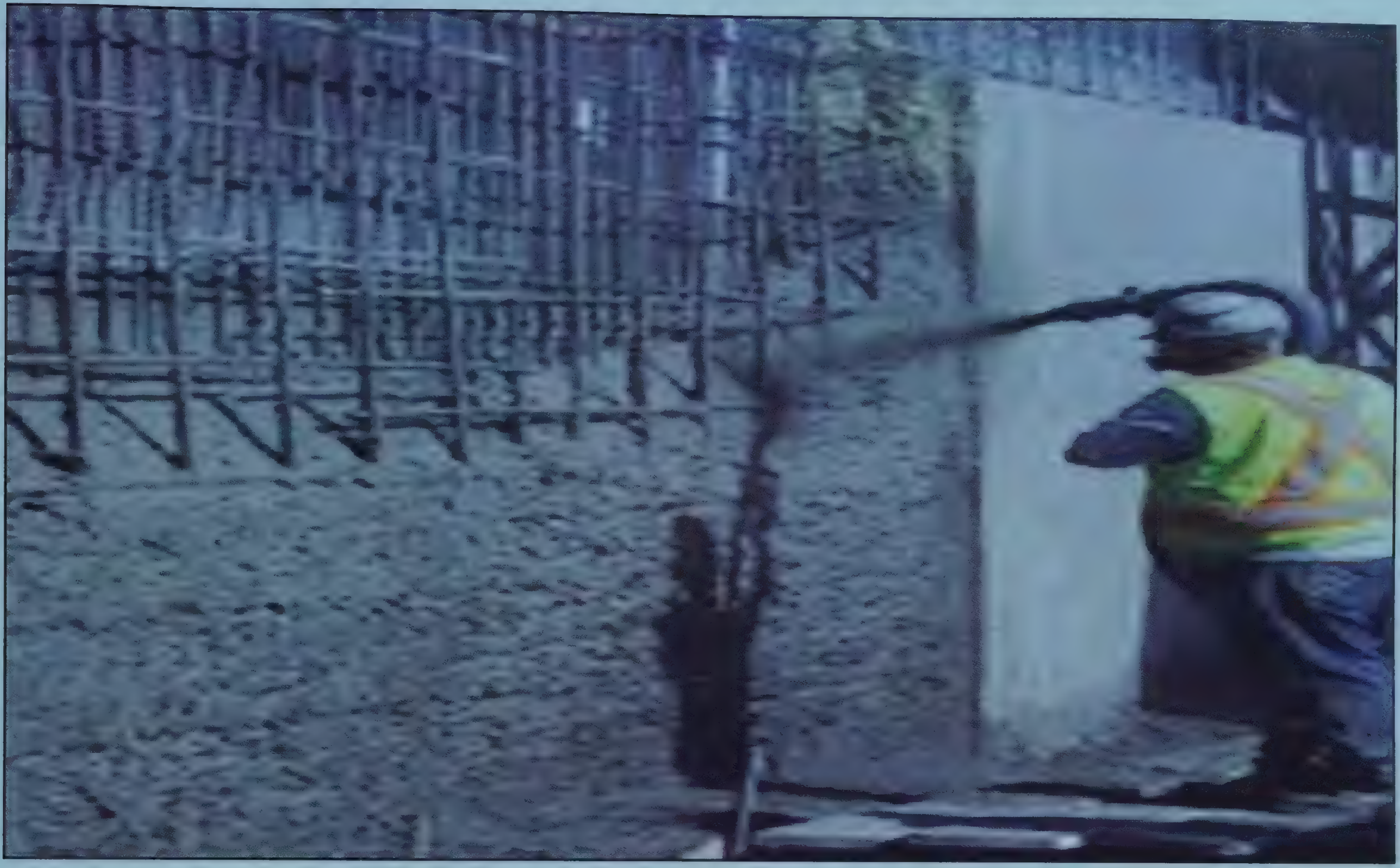


Fig. 4.28 Covering of Slope with Net and Shotcreting

B8. Ground anchors/ driven anchors (Active system)

(i) A pre-stressed grouted ground anchor is a structural element installed in soil or rock that is used to transmit an applied tensile load into the ground. Grouted ground anchors, referenced simply as ground anchors, are installed with grout filled in holes. Grouted ground anchors can also be referred to as “tiebacks”. The basic components of a grouted ground anchor are:

- Anchorage;
- Free stressing (un-bonded) length;
- Bond length.

(ii) These components of a ground anchor are shown schematically in **Fig. 4.29**. The anchorage is the combined system of anchor head, bearing plate, and trumpet that is capable of transmitting the pre-stressing force from the pre-stressing steel (bar or strand) to the ground surface or the supported structure.

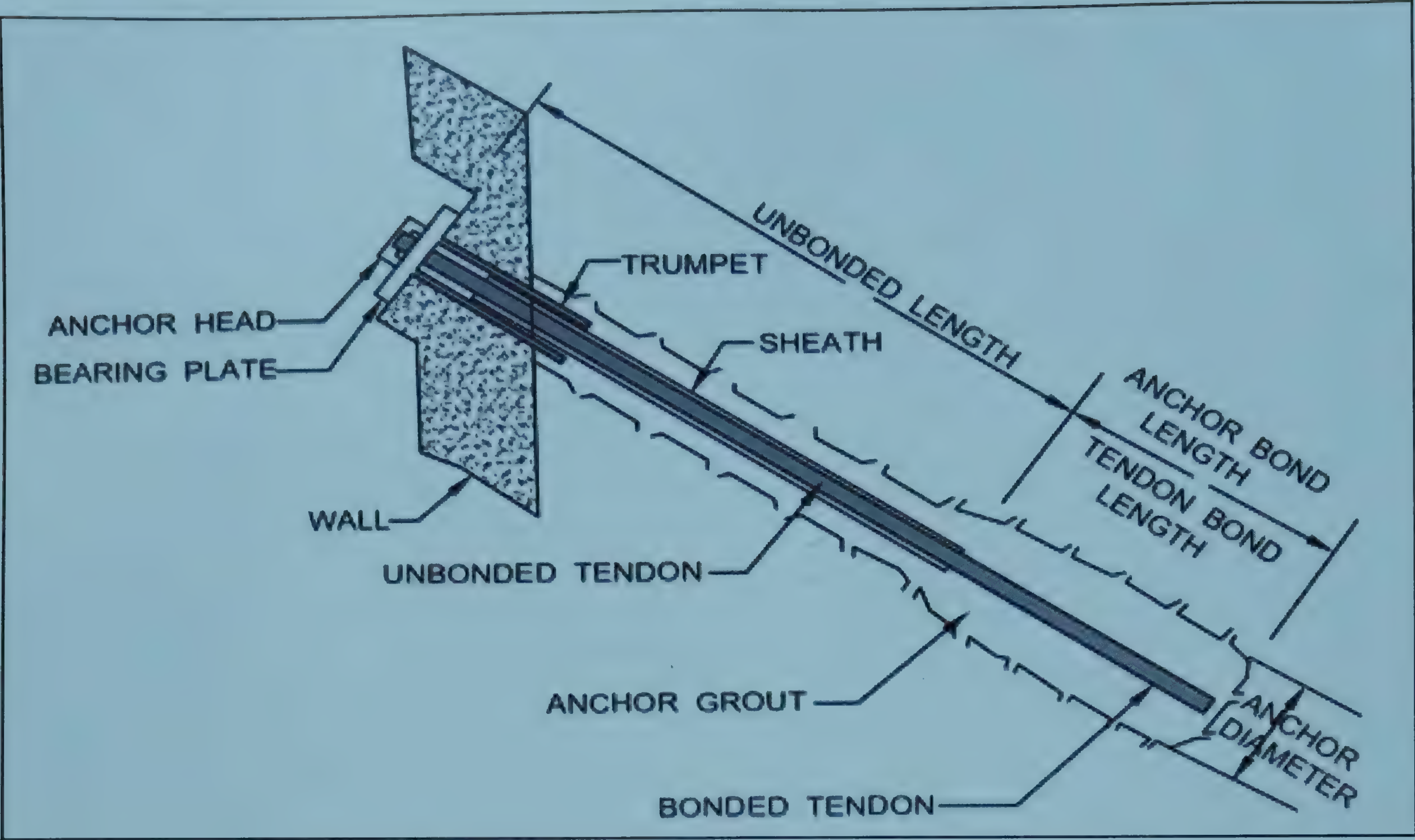


Fig. 4.29 Typical Components of a Ground Anchor

Prestressed anchors are used when it is required to stabilize a rock slope against the possibility of deep-seated failure. High tensile steel tendons or cables are commonly used to provide the prestressing force. However, before grouting fixed end of anchor, it is necessary to grout fissures in the rock. The procedure therefore should be, making the boreholes, water pressure test and if the borehole stands water pressure, grouting the fixed end of anchors. Otherwise, grouting the borehole and re-boring and grouting the fixed end of anchors thereafter. After the grout has set reinforcing cable is stretched to impart a calculated magnitude of pre-stressing force to the rock mass and then the cable is fixed to the anchor plate. Pre-stressed anchor is an expensive remedial measure and is used only where there is no other alternative.

B9. Micro Pile Works

(i) Micro piles are small diameter piles, which can be either drilled or grouted. The pile diameter is generally between 200 mm to 300 mm inclusive of metallic/ non-metallic or without casing and length varies. In order to stabilize slopes, micropiles are designed to provide the required restraining forces to stabilize the slope. Micropiles generally consists of a continuously threaded hollow reinforcing tendon as a load carrying steel member together with a grout of cement which allows transfer of tension and compression forces mainly from the friction of the threaded tendon via the grout into the surrounding soil. Due to high pressure grouting, there is insignificant shrinkage between the piles and the soil. The penetration of the fluid part of the cement mix into the surrounding soil creates a transitory zone between the body of the micropile and the soil leading to a strong grout/soil bond. Micropiles have been successfully used in soil reinforcement for slope stabilization/earth retention projects.

(ii) Micropiles are installed by methods that cause minimal disturbance to adjacent structures, soil, and the environment. They can be installed in access- restrictive environments and in all soil types and ground conditions. Micropiles can be installed at any angle below the horizontal using the same type of equipment used for ground anchor and grouting projects. Since the installation procedure causes minimal vibration and noise and can be used in conditions of low headroom, micropiles are often used to underpin existing structures.

(iii) If the soil is collapsible in nature TAM (Tube a Manchette grouting method involves the use of perforated pipe along with a special sleeve grout)/ consolidation grouting or self drilling bars may be used.

(iv) For structural and geotechnical design and construction of micropiles or minipiles, reference shall be made to FHWA NHI-05-039 ‘Micropile Design and Construction’, British standard BS EN 14199 ‘Execution of Special Geotechnical works-Micropiles’ and IRC:SP:109 ‘Guidelines for Design and Construction of Small Diameter Piles for Road Bridges'.

4.3.4 *Rockfall and Debris Flow Protection System*

Hill slopes composed of rocks are prone to generate rock fall and rockslide hazards. Falling rocks, especially, are highly dangerous to life and property because of the large momentum they acquire in motion. The volume of rock affected by instability may range from isolated boulders to enormous volumes involved in rockslides. It has been a common experience that long after the construction has been completed, rock fall or slide incidence can occur.

(a) Preventive Measures

(i) Removal of potentially unstable rock (Scaling and Trimming)

(ii) Reinforcing rock slope by anchors/bolts/nails for prevention of rockfalls with asuitable drapey system as facia(covered with high tensile nets)

(iii) Drainage systems to prevent rockfall.

(iv) Buttresses to retain and protect areas of weak rock and prevent rockfall

(b) Protection Measures

(i) Berms/ Benching as rockfall protection measures

(ii) Ditches

(iii) Rockfall Embankments

(iv) Rock Sheds

(v) Simple drapery System

(vi) Rockfall Barriers

(c) Retention Measures

(i) Secured Drapery system

(ii) Shotcreting and Grouting with weep holes

(d) Warning Measures

4.3.4.1 Rockfall Protection Measures

The following measures can be taken to increase the resisting forces or minimizing the disturbing forces causing the Rockfall and prevent any detachment and movement of rocks.

a) Buttresses to retain and protect areas of weak rock and prevent rockfall

Where a rockfall or weathering has formed a cavity in the slope face, it may be necessary to construct a concrete buttress in the cavity to prevent further falls. The buttress fulfils two functions: first, to retain and protect areas of weak rock, and second, to support the overhang. Buttresses should be designed so that the direction of thrust from the rock supports the buttress in compression. An indicative sketch of the buttress is shown in **Fig. 4.30.** In this way, bending moments and overturning forced are eliminated and there is no need for heavy reinforcement of the concrete or tiebacks anchored in the rock. If the buttress is to prevent relaxation of the rock, it should be founded on a clean, sound rock surface. If this surface is not at right angles to the direction of thrust, then the buttress should be anchored to the base using steel pins to prevent sliding. Also, the top of the buttress should be poured so that it is in contact with the underside of the overhang. To meet this second requirement, it may be necessary to place the last pour through a hole drilled down into the cavity from the rock face and to use a non-shrink agent in the mix.

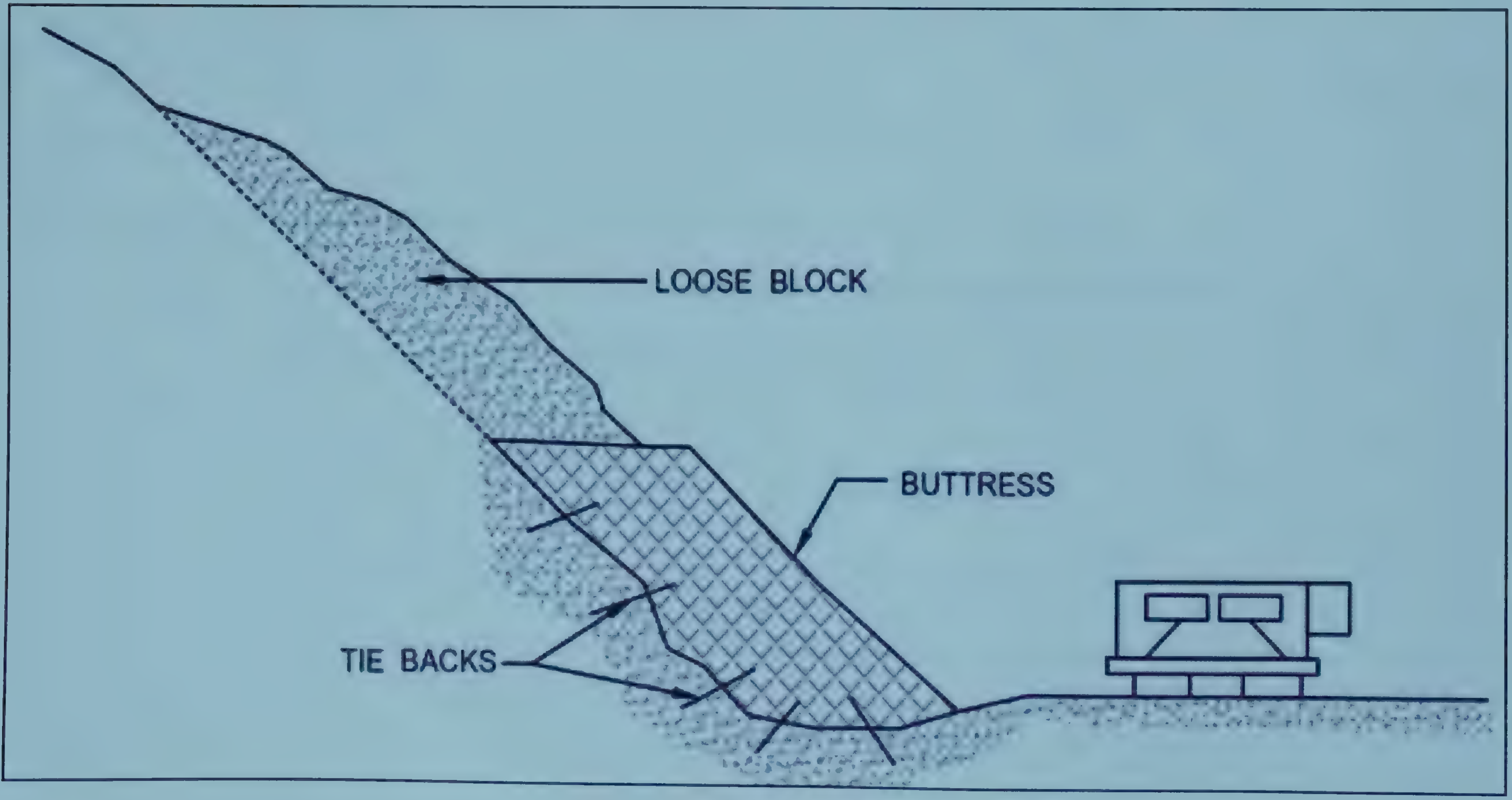


Fig. 4.30 Buttresses

b) Berms or Benching as rock fall protection measure

It is a popular technique used where a break in slope is required to restrict rock falls, especially in cut roads. These are very effective means of reducing the energy of rock falls and are frequently used on permanent slopes. Benches are flat catchment areas typically constructed at regular intervals. Benches are generally constructed at the base of durable strata with variable width ranging from 6-8m and the angle of the face depends upon the type of rock and its existing condition. Slope stability analysis using any of the standard techniques has to be performed to check the stability of the whole slope as well as the individual slopes made in the cut section. The choice of height, slope and width of bench depends upon the geology and shear parameters of the site and also the availability of space between the top of the slope and the road. For principle and general guidelines of benching for rock slopes, reference shall be made to FHWA-CFL/TD-11-002.

c) Ditches

Trenches are engineered and made at the toe of the slope to contain the falling rocks from the slope. Enough space availability is the critical parameter to be ascertained before adopting ditches as the permanent rockfall mitigation system. The selection criteria and analysis and design shall be as per chapter-6 of FHWA-CFL/TD-11-002. A typical sketch showing rockfall ditch as shown in **Fig. 4.31.**

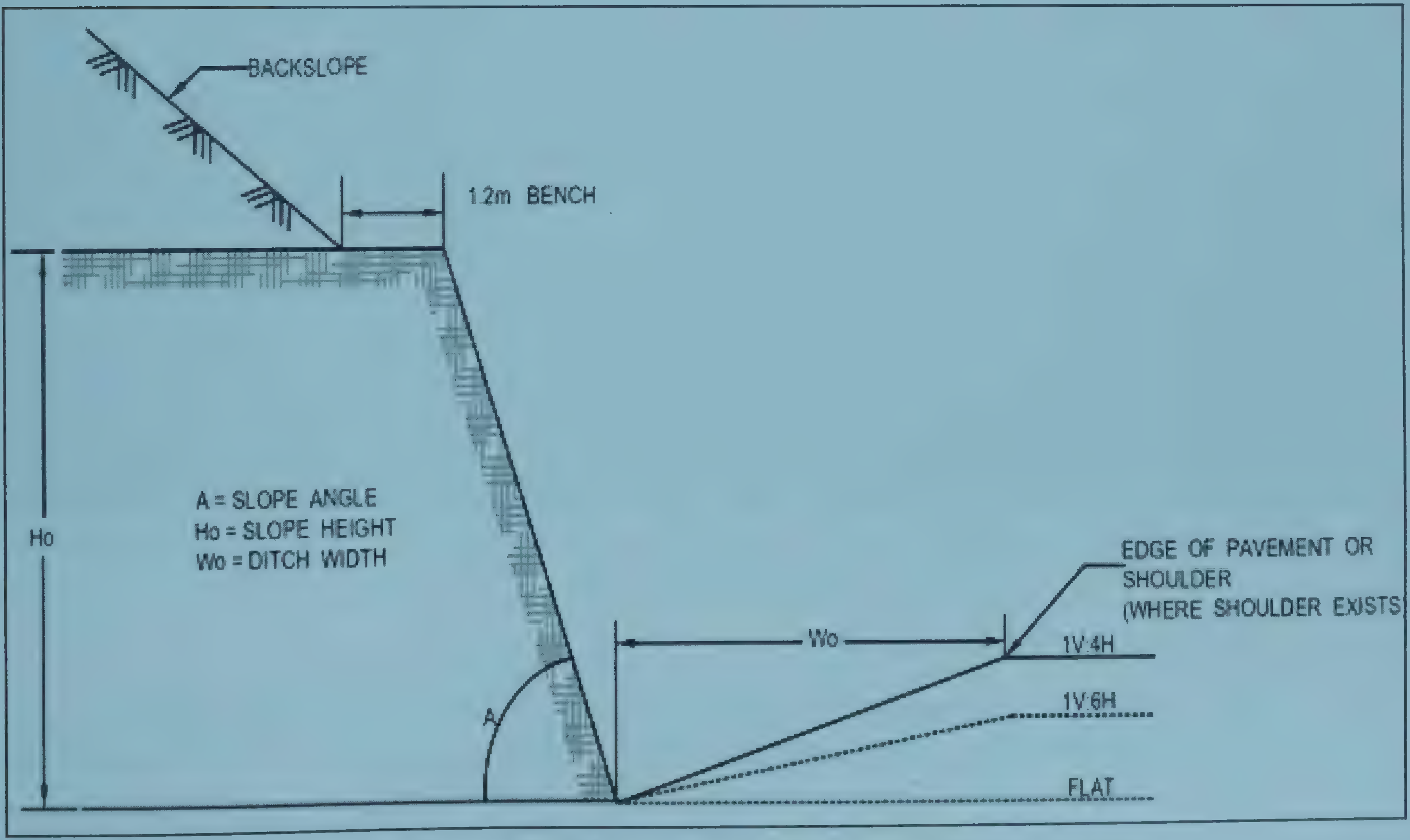


Fig. 4.31 Cross-Section a Typical Rock fall Ditch Design

d) Rockfall Embankments

Typical rock fall embankments are to protect infrastructure and roads, located at the foot of natural cliffs, in places where it is not possible to protect the whole slope, refer **Fig. 4.32.** The embankment can also be used in areas where debris flow, mudflow or landslides may occur. It is suggested to use flexible systems capable to absorb kinetic energy and impact for rockfall embankments. To make steep and high embankments, the common technology in use are double-faced reinforced soil system and self-supported gabion gravity wall offsetting to both sides. The location (distance from the slope), the height and the size of the embankment are evaluated concerning the slope morphology, the characteristics of the area and the kinetic energy of the falling rocks. Various types of rockfall embankments used for rock slope protection are given in chapter-6 of FHWA-CFL/TD-11-002. Rockfall embankments testing against impact and its realization is given in UNI 11167 (Rockfall Protective Measures - Ground Walls - Impact Test Method and Construction).

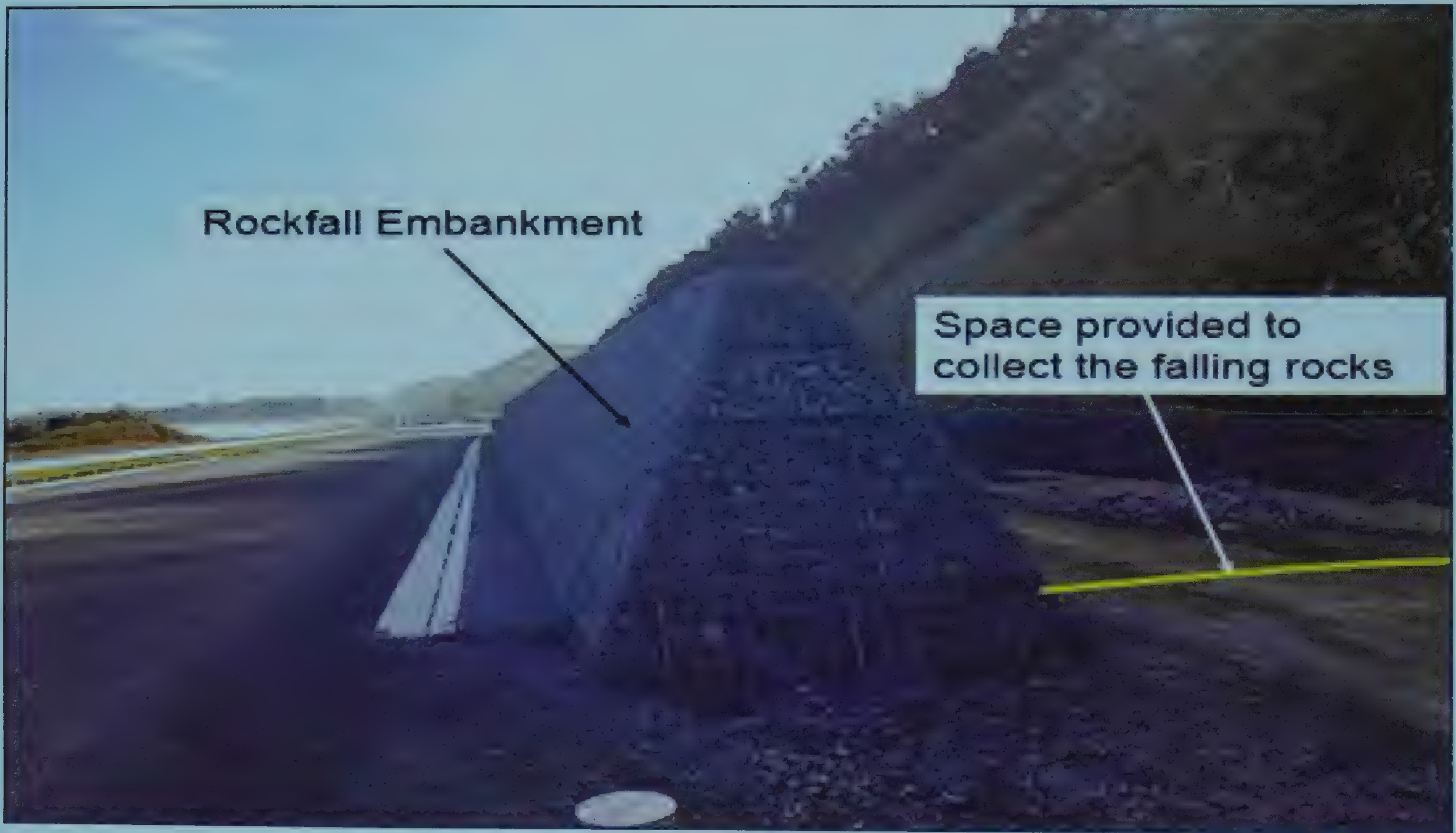


Fig.4.32 Rock fall Embankment to Protect Infrastructure and Roads, located at the Foot of a Natural Cliff

e) Rock Sheds

In areas of extreme rockfall hazard where stabilization of the slope would be very costly, construction of a rock shed or even relocation of the highway into tunnels may be justified **(Fig. 4.33)** When the rockfalls have a steep trajectory, the shed has a flat roof/portals with slab /arch shape covered with a layer of energy-absorbing material such as gravel. Sheds are constructed with reinforced concrete with steel reinforcement designed to withstand the worst-case impact loading at the edge of the rock. The design should also consider the stability under impact loading of the foundations for the outer columns that are often located at the crest of steep Rockfall Engineering by Duncan C. Wyllie. Rock sheds shall be constructed with a sloping roof that is designed to deflect rolling rock over the railway. Because such sheds do not sustain direct impact they can be of much lighter construction. Rock sheds are effective with high capacity of energy absorption and maybe an only suitable option in certain cases.

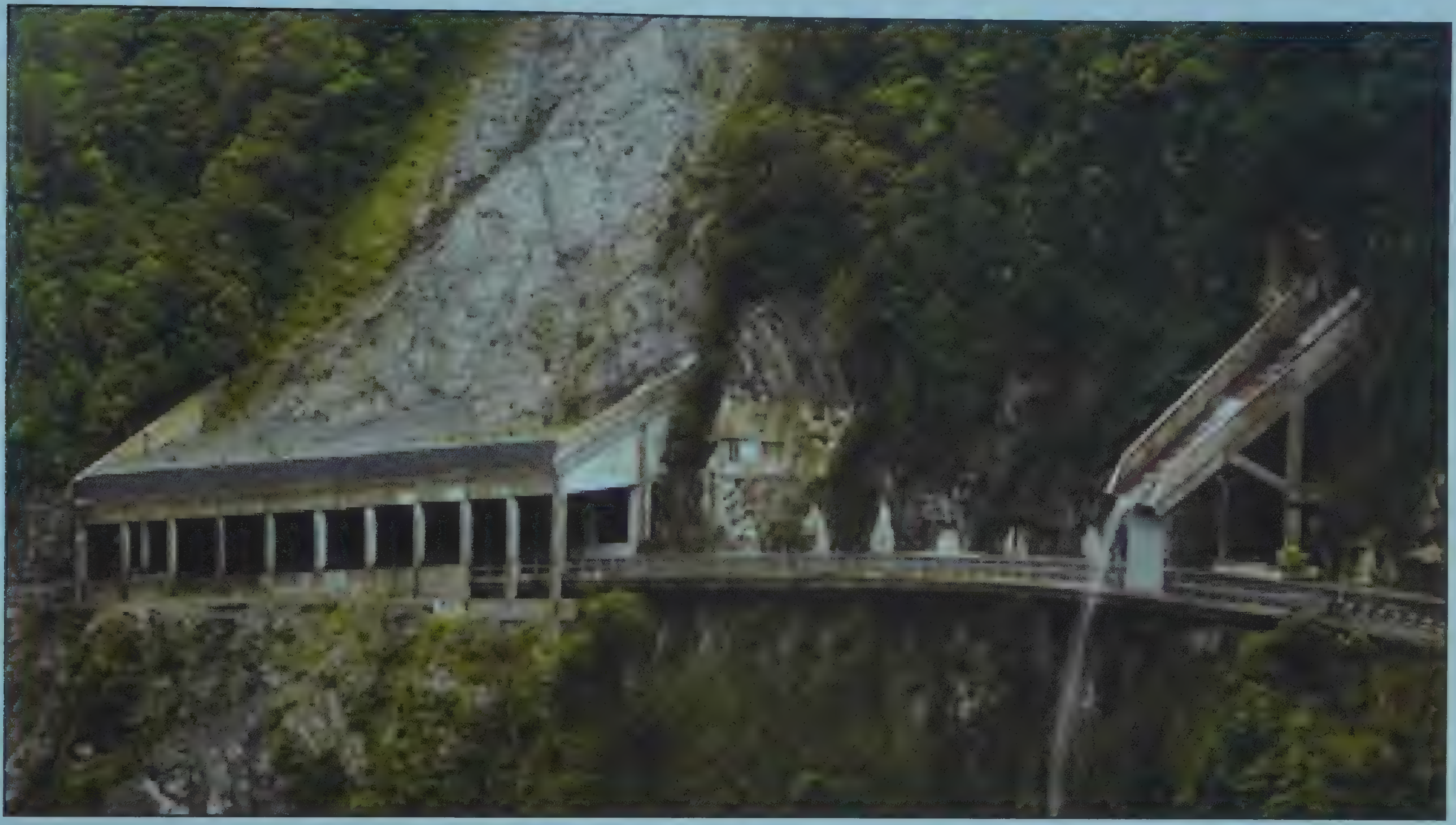


Fig. 4.33 Site Photograph of Rock Shed

f) Rockfall Barriers

These barriers intercept and stop falling rock and boulders from moving further down the slope. Barriers are designed based on various factors (e.g.: boulder size, slope parameters, rockfall simulations, etc.) and area adapted to the ground conditions. The requirement of all barriers is its flexibility upon impact. Barriers absorb impact energy by deforming, and systems with high impact energy capacity are both flexible and are constructed with materials that can withstand the impact of sharp rocks without significant damage. The following is a brief description of some commonly used barriers.

- **Concrete Barriers** are best suited to control low-impact energies and rollout from the ditch. Due to their extreme stiffness, higher impact energies can locally shatter the concrete (sometimes violently) on both sides of the barrier.
- **Earthen Berms** improves the effectiveness of the available containment area by creating a steepened for slope. It can provide considerable energy dissipation due to its large mass and loose surface characteristics.

Factors that influence the containment effectiveness of earthen berms, such as their position, width, shape, and substrate composition, shall be evaluated and optimized with rockfall modelling. Earthen berms are generally shaped with steep side slopes and a typical base width-to-height ratio between two and three. The base width can be reduced by incorporating large rocks or structural elements. However, at present, the impact capacity of earthen berms has not been well quantified.

- **Flexible Rockfall Barrier** is specially designed where it may not be possible to install rockfall drapery protection or surface stabilization mesh due to technical, topographic or economic issues. In these cases, a cost-effective solution is often provided by installing a dynamic rockfall barrier on the slope. These dynamic barriers are positioned to intercept and stop falling block and boulders. They are often supplied by specialized manufacturers a kit form for a specific height, length, and energy absorption capacity. It consists of an interception net or facia made of Cable panels / Ring Net Panels, which can be of different shapes like circular or omega shape etc. along with a secondary mesh for small boulders or combination of meshes along with the additional retaining layer of simple rockfall netting. Mesh is to be placed on the downslope side of the barrier. The posts shall act independently of the interception nets. The system should be so designed that even if a post is hit by falling block and damaged, the adjacent posts should be able to take the additional forces, ensuring that the catching performance of the rockfall barrier system is not compromised. During an impact, the system should ensure that the energy of the falling rock/debris is dissipated and prevented from moving any further. The lateral and upslope anchoring cables shall have energy dissipaters/braking system which should be able to absorb the applied energy by deformation and not by friction, thereby guaranteeing a better and longer-lasting performance. The advantage of the flexible barrier is that the barrier can withstand higher energies of impact up to 10000kJ due to its flexibility and standard testing methods have been developed to test the performance of these barriers. **Fig. 4.34** shows such a system in place on a highway.

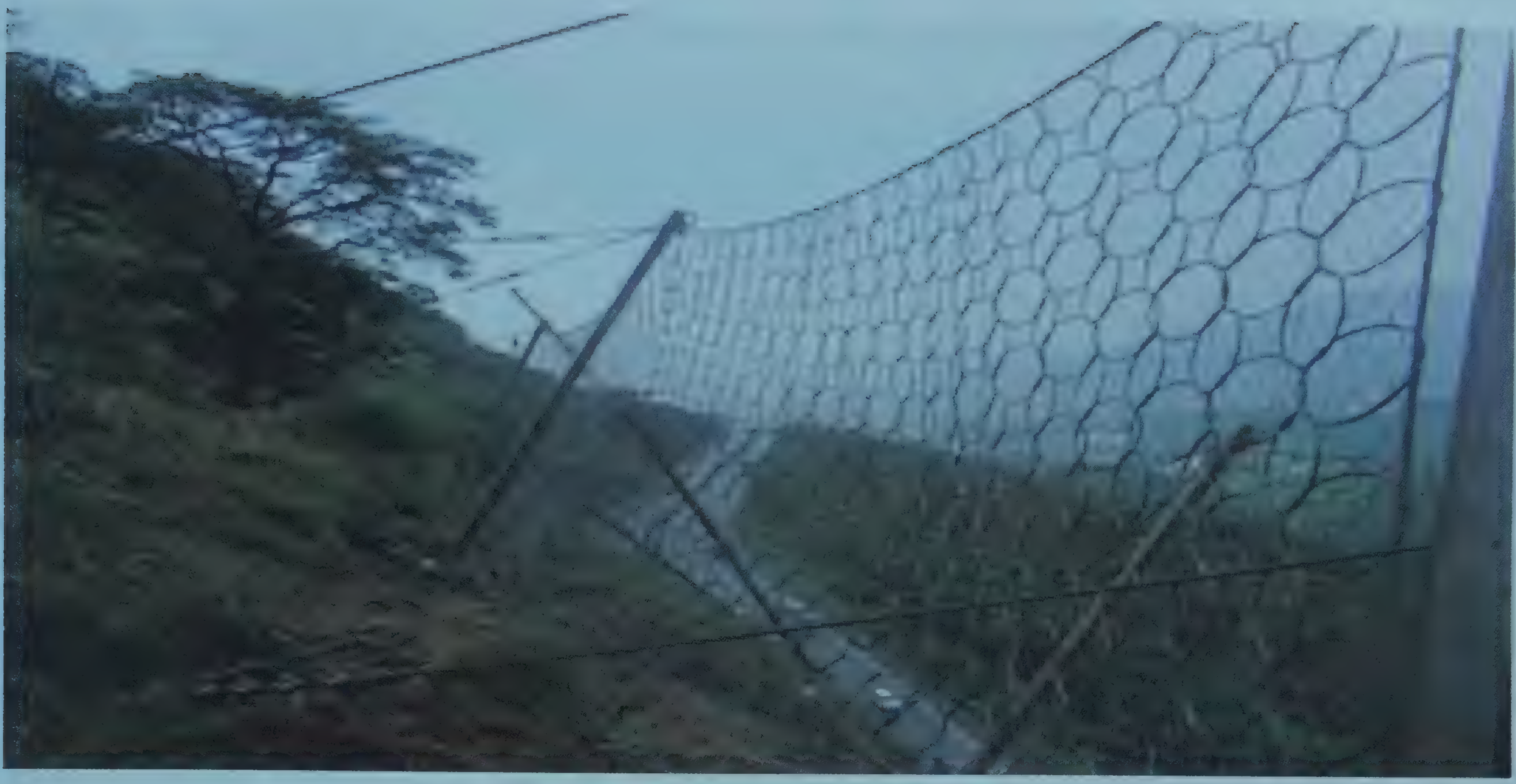


Fig. 4.34 Flexible Rockfall Barriers

The details of earthen berms, concrete barriers are given in Chapter-6 of FHWA-CFL/TD-11-002. Specification of interception net or facia made of Cable panels or Ring Net Panels shall be following the specification provided in ISO 17746, ISO 17745 respectively. The testing shall be done as per EAD-340059-00-0106 (by EOTA) or/and as per ONR 24810. The selection criteria, testing, analysis and design, specifications and installation techniques of flexible rockfall barriers shall be following UNI11211 part 4 Rockfall protective measures.

g) Warning Measures

Fences and warning signals that are triggered by falling rock are often used to protect highways and occasionally railroads. The Geological Survey of India (GSI) in consultation with a British company is extensively working to develop early warning systems for some parts of the country on a trial basis. Once the trails are successful, it will be developed for other parts of the country also. For further information, reference may be made to the GSI website.

4.3.4.2 Debris-Flow Mitigation & Emergency Measures

Debris flow is a phenomenon with high destructive force. It often constitute debris flowing with water in high energy. There are different structures which are good for mitigating debris flows like debris flow basins, check dams/weirs as deflectors, debris flow retaining walls and debris flow barriers. Among these structures, most tried and tested structures are debris flow barriers.

Debris flow basins are used in areas where debris flow must be slowed down, and debris must be contained. These basins will be eventually filled with deposits and must be cleaned periodically, or they will overflow. Their design will be in such a way as to contain maximum flow volumes of an area.

a. Structures for Mitigating Debris Flows

The following are some of the structures which can be used to mitigate the effect of debris flows on hill roads.

(i) Debris-Flow Basins

These catchment basins are commonly built at the base of slopes where debris flows are frequent. They are used especially in areas where the debris must be contained so that soil and debris are stopped from flowing into sensitive ocean or river shorelines areas or where there are structures at the base of the slope that is vulnerable to debris-flow damage. These basins will eventually fill with the debris-flow deposits and must be emptied periodically, or they will overflow. Commonly, large pieces of equipment such as dump trucks and power shovels are needed to empty the debris and carry it away. However, small basins can be emptied manually. They should be designed to be able to contain the maximum flow volumes of an area to prevent overtopping during a flow event.

(ii) Check Dams/Weirs as Deflectors

Check dams are small low drop structures built across a gully or channel to prevent it from deepening further. These small dams decrease the slope gradient and reduce the velocity of water flow and the erosive power of the runoff. They promote the deposition of eroded materials to further stabilize the gully or channel. Check dams are very effective in controlling debris flow. When installed on debris slides, the dams store raveled material, which eventually creates small terraces on the slide, reducing the surface slope. Check dams can be constructed of reinforced concrete, permeable structures like gabion boxes / mattresses, log cribs. Concrete mortared rock dams do not usually exceed 8 m in height, whereas log crib dams must not exceed 2 m. The spacing of dams depends on channel gradient and dam height. **Fig. 4.35.**

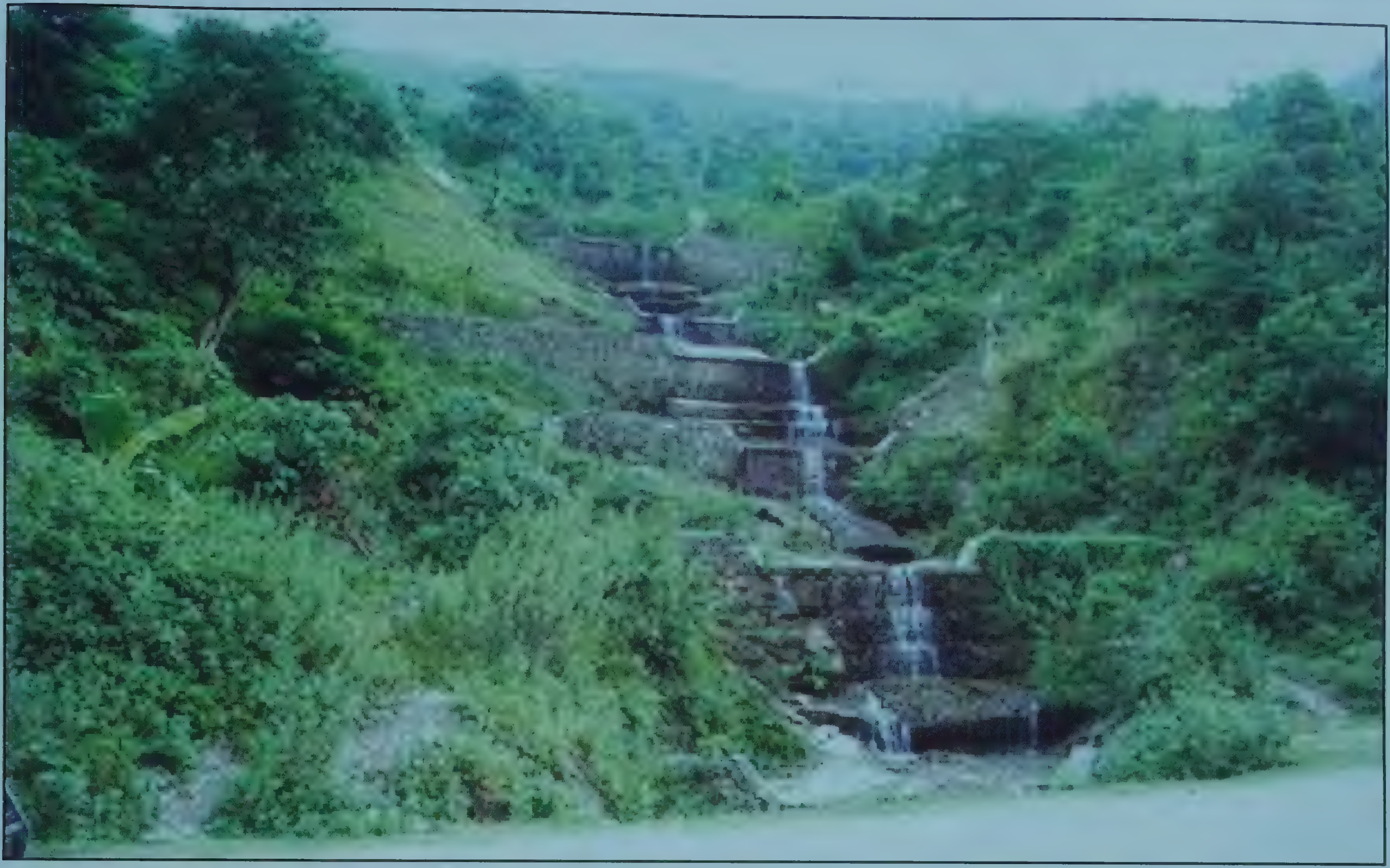


Fig. 4.35 Typical Photograph of a Check Dam in a Hilly Terrain

(iii) **Debris-Flow Retaining Walls**

These are structures that can be built on various kinds of materials. They are designed to stop the progress of the debris fall, either by blocking the flow or diverting it around a vulnerable area. These structures should be carefully designed as any deflection of the material may be unintentionally redirected into additional vulnerable areas.

(iv) **Debris Flow Barriers**

Debris flow is a fast-flowing mixture of water and a high proportion of solids (stones, blocks, boulders, timber) which moves downhill in channels in the form of a wave. A debris flow has a destructive potential comparable with rockfall, avalanche and high water. Debris flow barriers made of flexible ring nets withstands high static & dynamic loads **(Fig. 4.36)**. It basically separates the water from debris thus reducing the destructive force. Debris flow barriers are often used where the high static and dynamic loads are expected due to the high flow of debris, flexible ring net barriers are installed to effectively contain the debris. These can be installed with a low outlay of material and man-hours, greatly reducing costs and construction time. The testing shall be done as per EAD-340020-00-0106 (by EOTA).

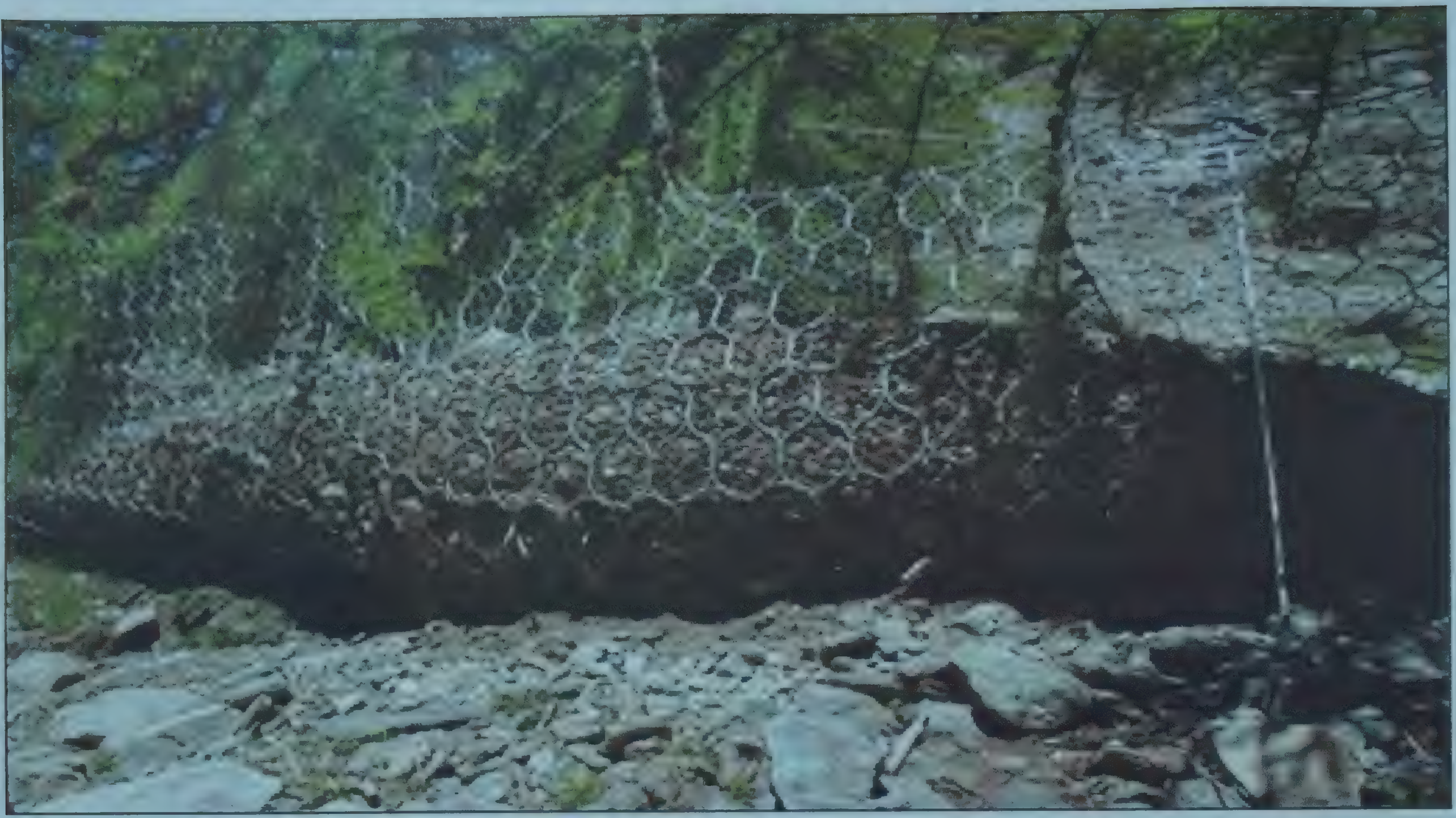


Fig.4.36 Debris Flow Barrier

(v) Emergency Protection Measures

The emergency protection measures are often used to support rapid responses to emergency situations immediately after a rockfall /landslide, debris-flow events, as well as during ongoing projects involving earthwork, slope stabilization etc. There is a little time to react to sudden effects of landslides and floods in remote and hard to reach areas. Hence the emergency protection measures must be rapid and effective in order to restore the natural status of the impacted region, to contain the damage and lives can be restarted. When the road user's safety is having a significant impact, emergency restoration works of roads shall be arranged promptly by the road owner or his maintenance agent, who should ensure that a competent contractor is engaged to carry out the work. Effective communication shall be maintained among the various parties involved in the inspection of landslide, preparation of the specification and in the supervision and acceptance of emergency restoration works.

To deal with emergency situations, speed and efficiency of installation are vital. Protection works shall be:

- Rapid and simple to deploy
- Flexible and light
- Simple connection between units
- Uses locally available fill material
- Easy transportation
- Re-usable

4.4 Instrumentation and Monitoring

4.4.1 Field instrumentation and monitoring is a requirement for detecting signs of impending instability as well as post-slide movements. Observational data on vertical and lateral surface and sub-surface movements, and piezometric pressures within the unstable slopes are necessary for evaluation of stability and design of control measures.

4.4.2 The instrumentation programme should be planned to provide the basic information of the following aspects:

a) Monitoring of the build-up and dissipation of pore water pressure at different points in the slide area especially around the failure plane. This action should be taken well in advance to control adverse situation in future.

b) Measurement of sub-surface movements and by installing borehole instruments like VM Piezometer. Rod Extensometer's in-place inclinometer's as their output can be easily transmitted through a wireless network to a safe & remote location or control Room.

c) Measurement of surface movements, by installing Electronic crack, wire-rod extensometers, tilt meter's etc. VM Load Cells for rock bolt/cable anchor application's as their output can be easily transmitted through a wireless network to a safe & remote location or control room.

4.4.3 *Monitoring of Pore water pressure*

Monitoring pore pressure is essential for affective **stress** analysis of the slide prone area. Pore pressure measurements are required specially around the failure **planes** for control measure to be adopted as well as for mitigating potential slides. Piezometers are installed for this purpose in the drilled boreholes.

4.4.3.1 *A Number of piezometers are available for this purpose*

These piezometers are broadly classified into three categories.

(a) Hydraulic piezometer

(b) Pneumatic piezometer and

(c) Electrical piezometer (Vibrating Wire Type).

4.4.4 *Monitoring of sub-surface movements*

Analysis of a slide gives an indication of probable failure arc. Normally, the sliding surface cannot be observed visually, nor it is apparent from surface measurements. This acknowledge of actual deep seated failure plane is of use in back calculation of factor of safety and for properly understanding the mechanism of sliding. Instrument mentioned under 4.4.2 (b) above can also be used effectively. The data is also of utility in designing remedial measures such as restraining structures. Inclinometers enable quantitative measurement of lateral movement of slopes. The instrument not only gives the lateral movement but also reveals the direction of movement and rate of lateral movement.

4.4.5 *Monitoring of surface movements*

4.4.5.1 Surface movements may be horizontal or vertical. Horizontal movements are measured with surveying methods & by Wire rod extensometers. This primarily involves distance measurements. Vertical movements are measured with settlement gauges & by borehole sensors mentioned (refer 4.4.2 b) above. To measure the subsidence or horizontal surface movement pegs or surface markers are fixed at a number of predetermined points on the surface. Their vertical and horizontal position can also be are monitored periodically with the help of theodolite. With the advent of electronic distance measuring devices, called EDM devices, the same can be used for monitoring surface movements. All the measurements are taken from a fixed observation post or permanent bench marks which are installed at a place not likely to have any disturbance and is located away from the zone of slide.

4.4.5.2 Apart from the general surveying methods, photo-grammatic methods, surface wire rod extensometers, rock gauges, convergence gauge of various types using mechanical, electrical or electronic gadgets are also used in monitoring surface movements.

4.4.5.3 Surface vertical movements are also measured with platform gauges, extensometers, Hydraulic settlements gauges mercury settlements/heave and magnetic settlement/heave gauges, In-place inclinometers combined with Rod extensometers for monitoring vertical settlements. Surface movements (Tilt/rotations) can be easily monitored with tilt meters. This also contains a gravity sensing transducer which may be mechanical, electrical or electronic.

4.4.6 *Techniques for Monitoring of Natural Hazards*

A good prediction and forewarning system must be implemented with effective efforts to control and mitigate landslides, slope failures, rockfall protection systems, avalanche or similar natural hazards, to reduce the vulnerability against destruction caused by natural forces. These destructive forces require monitoring systems that can be accessed remotely using advance wireless transmission system or in-situ to provide an immediate warning, in case of failure.

Slope monitoring systems can be classified in the following four categories. Slopes monitoring system shall be chosen based on geographical information, terrain requirement, intensity of the hazard, vulnerability of natural forces to site specific conditions and best engineering practices.

A. Geodetic Methods

Geodetic methods must aim to record surface data under a wide range of environmental conditions. Tool are used for assessing hazards through monitoring the change of surface. Some of the tools that can be used for similar monitoring are as below:

(i) LIDAR/ 3D Terrestrial Laser Scanning (TLS)

(ii) Global Positioning System (GPS) provides “Location, velocity & time synchronization” using US based Satellites.

(iii) Global Navigational Satellite System (GNSS) provides same information as GPS, but with much more accuracy & precision, as it can track (US based & all other global Satellites).

(iv) Robotic total station with software & Prism Targets.

(v) Digital Photogrammetry.

(vi) SAR-Synthetic Aperture Radar/Slope Stability Radar (SSR)

LIDAR/ 3D Terrestrial Laser Scanning (TLS) must generate all the point clouds from the area, and any change on the surface can be differentiated by the point clouds coordinates.

GPS shall be able to measure displacements to evaluate slope stability. During the survey, monuments shall be placed on the stable ground covering a slope area as reference points. The coordinates of the monuments shall be periodically determined at certain intervals. The characteristics and types of displacement are evaluated by studying the behavior and rate of point change.

B. Geotechnical Methods

Geodetic survey gives a surficial understanding of a location. In order to enhance it's (Geodetic) reliability, it is therefore required that geotechnical methods, e.g., TDR, in place Inclinometer, Rod Extensometers & VW Piezometers, and fiber optic sensing (Fiber Bragg Gratin- FBG Technology), Geophysical methods, e.g., seismic methods, shall be adopted to complete the assessment of slope stability.

These methods allow one to obtain more detailed geological and physical descriptions of soil materials as well as to define the vertical boundary of the slope. It is also found that TDR, In-place Inclinometers, Extensometer & VM Piezometers), Fiber Optic Sensing (FOS) and other similar geotechnical methods can carry out real time monitoring of slopes, by using combination of wireless sensors/GSM/GPRS, FO Cable etc. Some methods adopted for synthesizing the information based on data obtained from the following processes.

i. Time Domain Reflectometry (TDR)

ii. Fiber Optic Sensing (FOS) using Fiber Bragg Grating (FBG) optical sensors & Optical Fiber cable's.

iii. Geotechnical & structural monitoring sensors using vibrating wire/ MEMS (Micro Electric Mechanical System) based sensors, with Data loggers with GSM/GPRS or wireless data transmission using (Nodes and Gateways) for remote data transmission.

C. Geophysical Methods

Slopes can be vulnerable to instability triggered by sustained wetting or drying events. The resilience of earth structures to these climatic stresses, can be difficult to determine due to the complexity of fill materials, deposits and the limitations of current approaches to characterization and monitoring.

Geophysical monitoring shall be principally applied at ground surface to measure the subsurface physical properties (e.g., seismic, gravitational, magnetic, and electrical) as well as anomalies in those properties.

The technique must be able to support the determination of time-invariant (i.e., geometry, sliding surface location) and time-changing (i.e., saturation, mechanical properties and rheology) features.

i. Electrical Resistivity Technique (ERT)

ii. Acoustic Emission (AE)

While each site is considered unique with respect to the survey design, the methods that most often prove to be favorable include seismic refraction, multichannel analysis of surface waves, resistivity tomography and ground conductivity scanning shall be used in combination or unison.

Primary targets for geophysical monitoring shall include compressional and shear strength of the rock and overlying sediments together with their relative clay and water composition.

Acoustic Emission (AE) shall be additionally considered for vulnerable locations. The Acoustic Emission technique is often capable of detecting pre-disaster deformation, so that an early warning can be given to allow for evacuation, which may also facilitate capturing of the slope derivation for detailed investigation and effective remedy.

D. Remote Sensing

Important information about landscape, geology, hydrology, vegetation as well as land usage are readily obtained from field observation and satellite image interpretation. The advance techniques that may used are as mentioned below:

i. Synthetic Aperture Radar (SAR)

ii. Geographic Information System (GIS)

A Synthetic Aperture Radar (SAR) system shall be based on microwave technology which can operate for both short- and long-term geo hazard monitoring. The monitoring can be remotely carried out without a direct installation of sensors on the strata. Thus, it may provide an effective alternative solution for satellite survey or relative interpretation.

GIS shall be able to acquire surface horizontal motion data that indicate the topographical expression of slope failure. Motion data concerning a slide that would have massed down inside the rock and the soil cannot be accessed by using GIS System. Hence, geotechnical methods must be used in tandem to enhance the accuracy and to arrive at logical conclusions.

The aforesaid monitoring systems to be applied in the field are not exhaustive. Additional method can be adopted as per suitability of site requirements and site conditions.

E. Data Transmission & Real Time Monitoring

Data transmission is an important aspect of monitoring system. Unusual movements that can trigger catastrophe, must be alarmed through GP Multi-antenna deformation monitoring systems.

A multi-antenna GPS deformation monitoring system **(Fig. 4.37)** must be installed to provide high precision GPS-derived coordinate solutions of multiple monitoring points using minimum one GPS receiver.

The system shall consist of (at least) one GPS receiver connected to required number of GPS antennas. A coaxial switching device enables data from the antennas to be sampled sequentially. A radio communication system shall be used to transmit the raw GPS data from the remote stations to the master control station. It shall be able to synthesize the data by itself and transmit requisite information to the end user.

The system must be capable of operating on an episodic or on a continuous basis. A dedicated radio system transmitting data from the antenna to the receiver shall be used to enhance the technique for slope or natural hazard monitoring and other deformation applications. The application must be able to trigger an alarm (in terms of hooter, text messages, pop-ups etc.), once it violates the threshold limits set by site authorities.

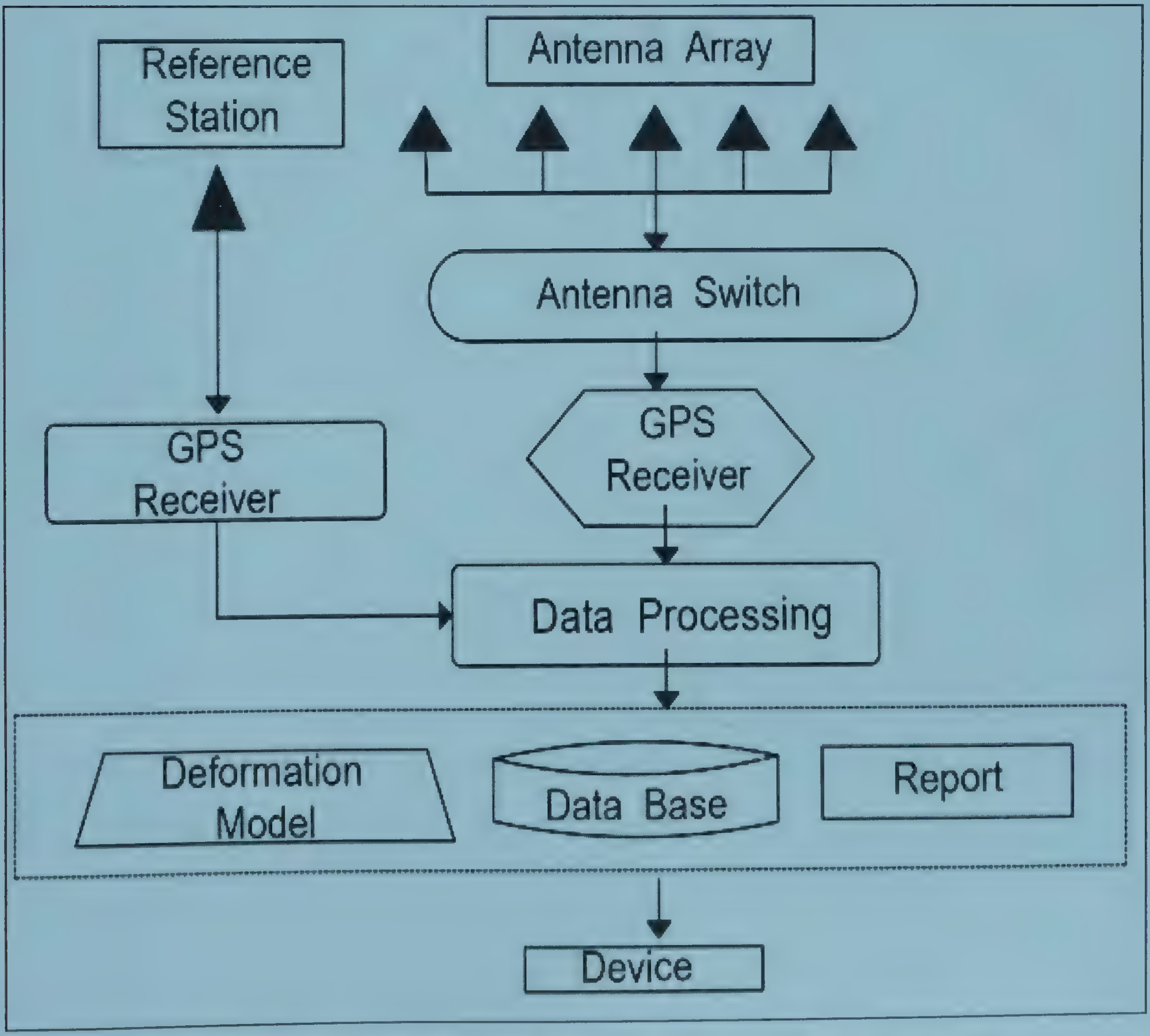


Fig. 4.37 Data Transmission & Real Time Monitoring

4.4.7 *Proforma for Data Collection*

A systematic collection of data helps in proper study of landslide problem thereby leading to a correct identification of landslide mechanism and choice of appropriate remedial measures. Use of standardized proforma for data recording also helps in setting up a data bank of landslides and interchange of information between experts belonging to different disciplines concerned with landslide studies. The correction of landslides continues to be as much of an art as a science. Properly recorded and analyzed case histories are of unique value in evaluation of the range of applicability of various theoretical models used in the analyzed case in the analysis. Further, stability and efficacy of remedial measures can also be determined with the help of such recorded case histories. A proforma for collection of data regarding landslides is given in Chapter 3 under para 3.4.

5. PAVEMENT DESIGN

5.1 General

5.1.1 Design of pavement for roads, whether in plains or hills follows the same basic principles like soil and traffic parameters as also climatic considerations and their effects. However, while designing pavement for hill roads, specific aspects relevant to the hill regions like terrain and topographic conditions, extremes of weather conditions, altitude effects like snow, frost susceptibility, serious drainage problem landslides etc., have also to be duly considered and suitably incorporated in the design so that the pavement is able to perform well for the designed traffic and service life.

5.1.2 The main features that require consideration for design of pavement in hill areas, not normally met within the plains, are as follows;

a) Whereas the road bed or sub-grade materials in the plains tend to be more or less homogeneous (mainly due to forming sub-grade by borrowed material) and fine grained, the road bed/sub-grades in the hilly regions are mostly mixtures of gravel, boulders, various types of rocky material etc. with some fine-grained soil matrix (the material forming the hill itself becomes road bed material).

b) Hilly regions normally receive very high rainfall (reaching as high as 1200-1500 mm annually in certain areas) spread over 6 months or so with very high intensity for short duration. This results in saturated road bed for prolonged periods and creates problems of drainage of pavement, erosion and instability.

c) Thermal stresses caused due to large temperature variation in atmosphere from time to time.

d) Rarefied atmosphere at high altitude gets exposed to higher degree of solar radiation and has effect on performance characteristics of materials like bitumen which tends to become harder and brittle.

e) Some regions in high altitudes (and even at lower altitudes in Northern Himalayan ranges) receive snow fall with some areas remaining snow bound in winter. Apart from extremes of cold and problems of snow clearance, issues like frost heave, icing, repeated freezing and thawing create problems of design, composition, construction, drainage and maintenance of pavement.

f) Road construction period available in high altitude and snow fall areas is very limited and design of pavement and selection of materials for same need special consideration so that the work is done with speed in the limited working season.

g) The cut formation, which serves as a sub-grade, shall be prepared to achieve the desired CBR and to receive the sub-base/base course as directed by the Engineer.

- Where the material in the subgrade in cut formation has a density less than specified, the same shall be loosened to a depth of 500 mm and compacted in layers in accordance with the specified requirements adding fresh material or cementitious material, if any, to maintain the formation level as shown on the drawings. The in-situ material can also be modified mechanically or chemically as per provisions of IRC:SP-89.

- In case the soil is found to be very wet or saturated to a considerable depth and removal is difficult, a capping filter layer consisting of coarse granular material as per table 400-1 "Grading of Granular Sub-base Material of MoRTH Specification" with sufficient permeability or alternatively geo-cell filled with granular material along with geotextile at base for separation cum reinforcing layer can be used to provide a firm support to the subsequent layers of pavement crust. The layer thickness of any of the above alternatives shall be decided as per the site condition.

- In rocky formations, the surface irregularities shall be corrected and the levels brought up to the specified level with granular sub-base material to be laid and compacted in accordance with the respective Specifications. After satisfying the density requirements, the cut formation shall be prepared to receive the sub-base/base course.

h) Embankments built against hill slopes can impede groundwater flow from the uphill side of the slopes. Similarly, roads may interfere with natural groundwater paths when a thin permeable soil cover is removed, and the road built up onto the rock or impermeable fill underneath. In such a situation, it is required that a permeable fill below the subgrade or embankment as shown in **Fig. 5.1** shall be provided. Such an arrangement will facilitate the free flow of drainage and improve the overall stability of the hill slope. To do so, excavate below the soil bottom and use a permeable fill-blanket at the bottom at least by half a meter below the subgrade/ embankment. This layer may consist of clean pit-run gravel, free-draining sand, or other suitable local materials. If springs or concentrated flows are encountered, drain-pipes may also be required.

Where supplies of coarse aggregate are limited, trenches can be cut below the subgrade and backfill ed with gravel (Squamish culverts) as shown in **Fig. 5.2**. The trenches should be about 1 m^2 in cross-section and spaced at 10 to 20 m intervals depending upon the site condition. To ensure that drainage does not get clogged with time, it is suggested that after the trenches are excavated geotextile fabrics are laid into it. The backfill gravel is placed on to fabric and the fabric is folded over the top of the drain material. A non-woven fabric meeting the requirements as per Section 700 of MoRTH shall be used. The gravelly material to be used for such purpose shall have permeability not less than 5×10^{-4} m/s.

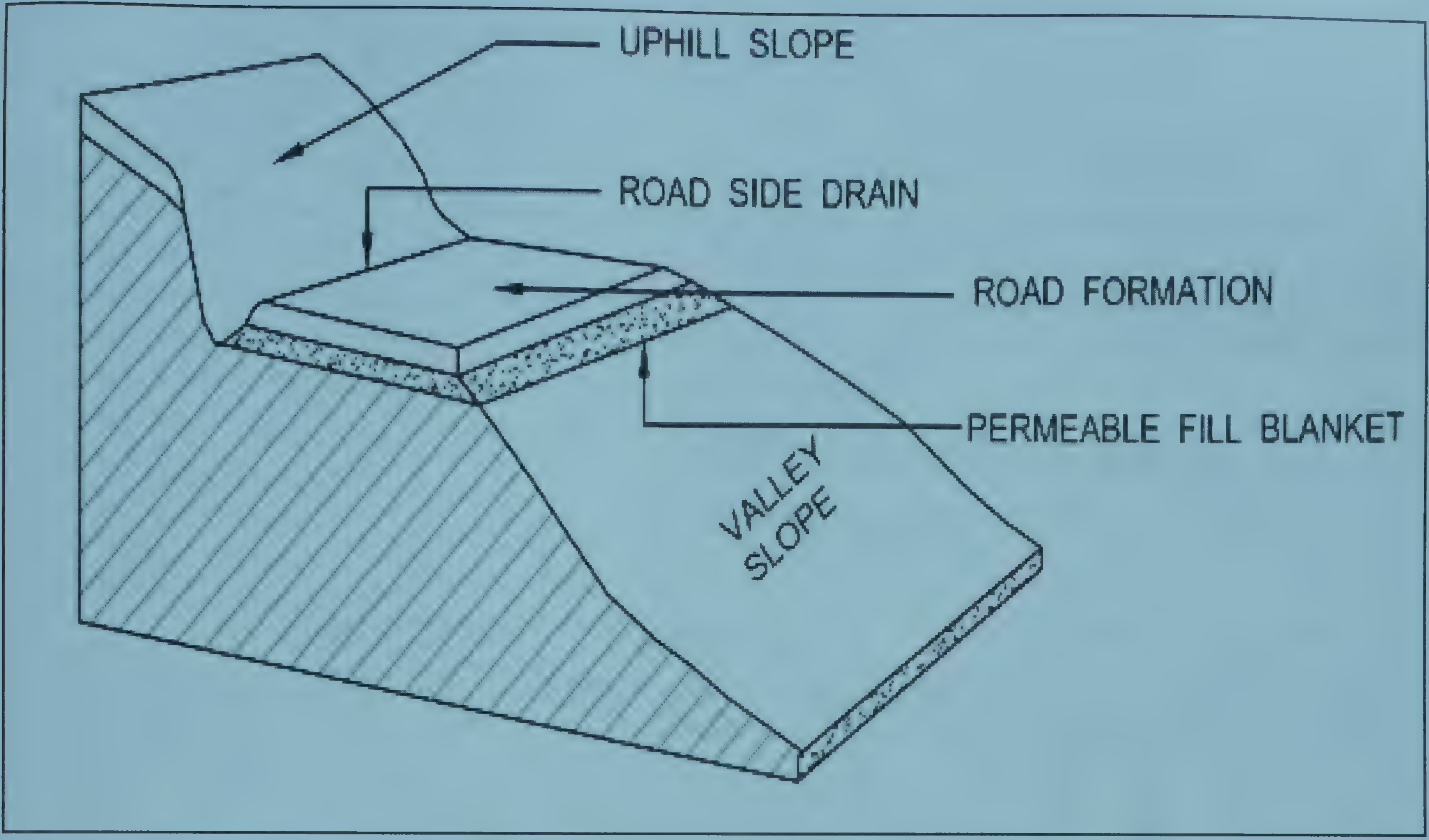
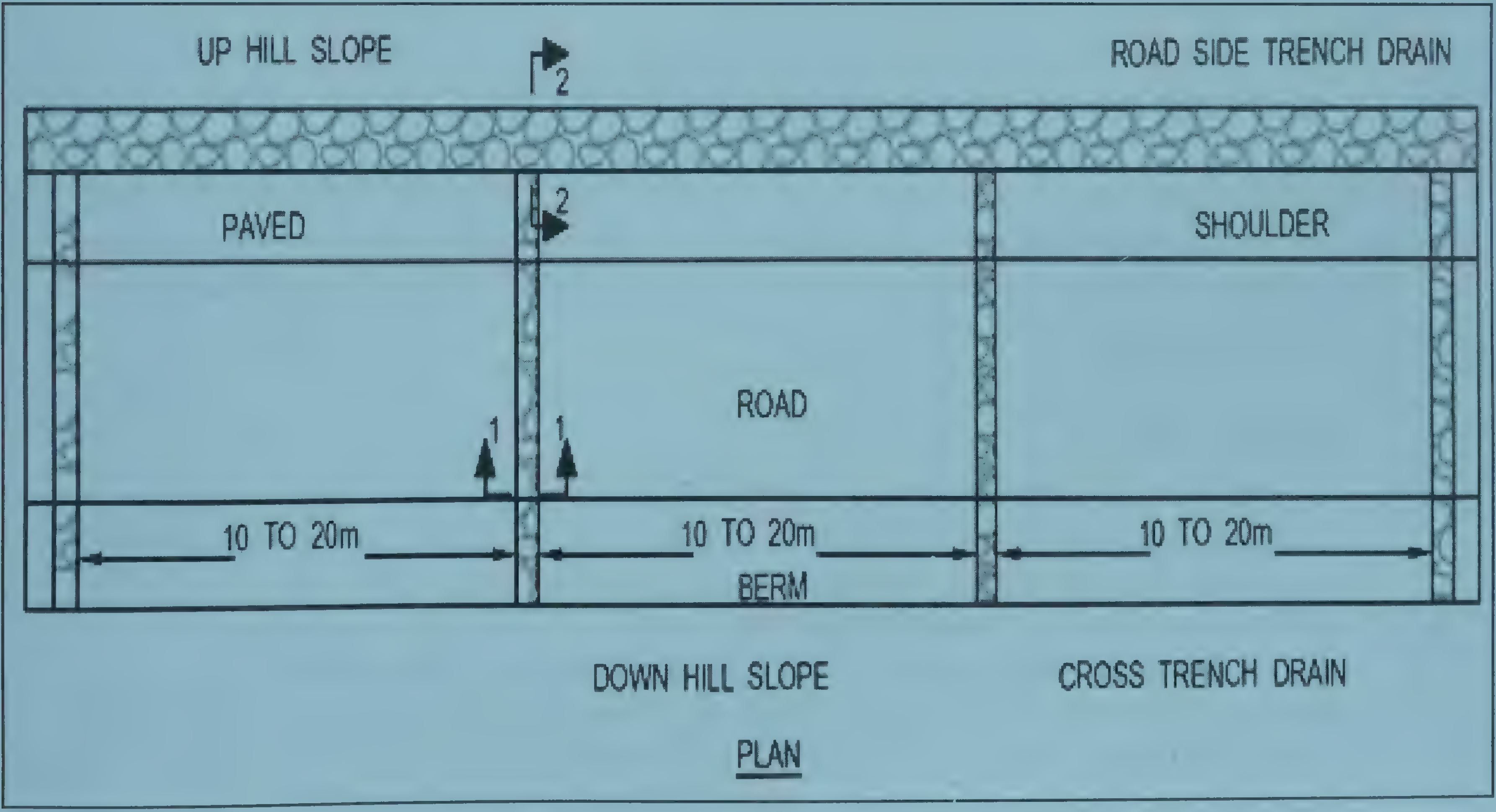

UPHILL SLOPE
ROAD SIDE DRAIN
ROAD FORMATION
PERMEABLE FILL BLANKET
VALLEY SLOPE

Fig. 5.1 Permeable fill below Embankment/Subgrade showing Stripping of Unstable Surface Material as a Slope Prevention Measure, Filter Material ensures Drainage at the base and improves Stability


UP HILL SLOPE
2
ROAD SIDE TRENCH DRAIN
PAVED
2
SHOULDER
ROAD
1
1
10 TO 20m
10 TO 20m
BERM
10 TO 20m
DOWN HILL SLOPE
CROSS TRENCH DRAIN
PLAN

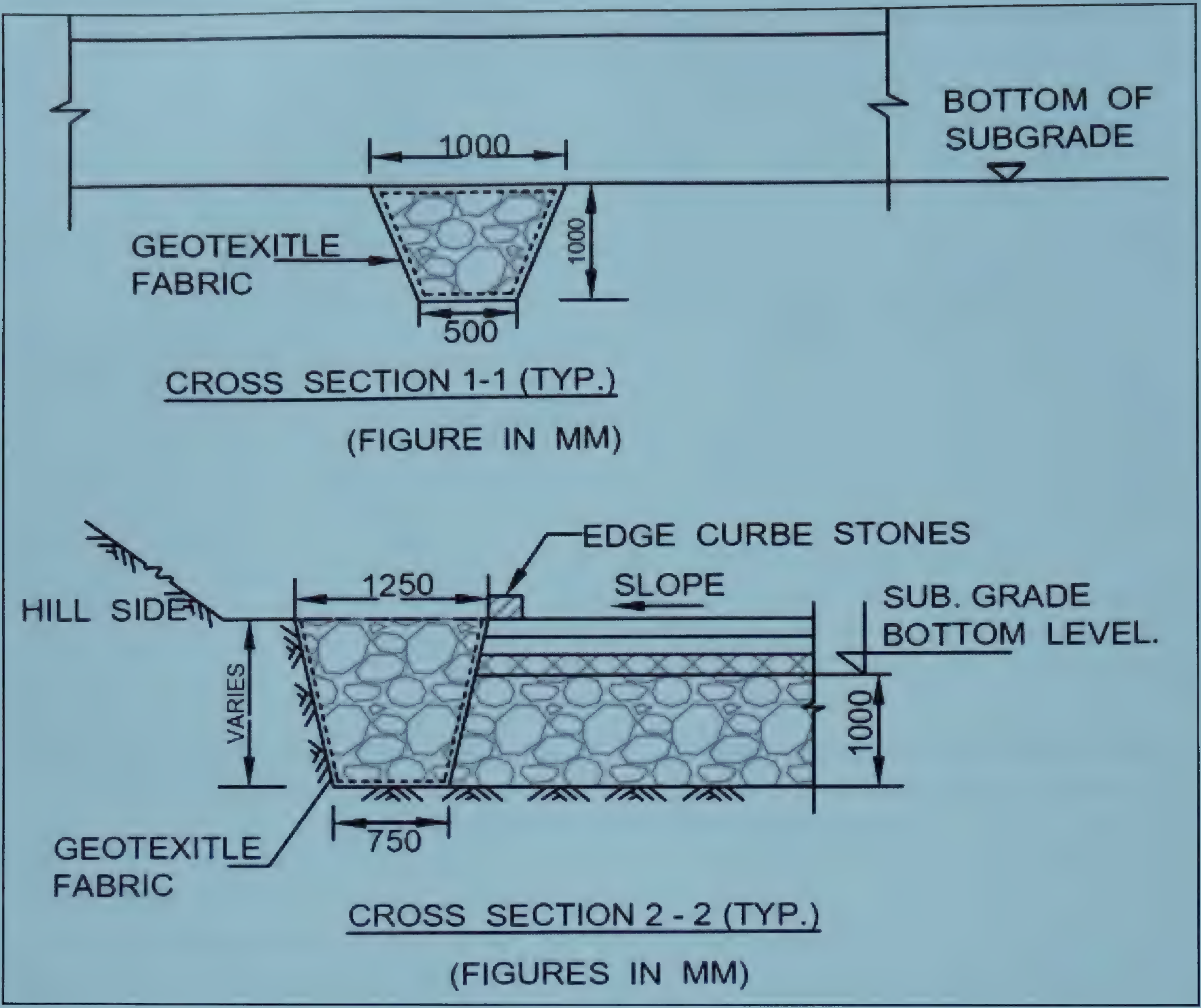

BOTTOM OF SUBGRADE
1000
GEOTEXITLE FABRIC
1000
500
CROSS SECTION 1-1 (TYP.)
(FIGURE IN MM)
EDGE CURBE STONES
1250
SLOPE
HILL SIDE
SUB. GRADE BOTTOM LEVEL.
VARIES
1000
750
GEOTEXITLE FABRIC
CROSS SECTION 2 - 2 (TYP.)
(FIGURES IN MM)

Fig. 5.2 Typical Plan Layout / Cross-Section showing Cross Trench Drains below Subgrade layer for quick disposal of Water from Uphill Side to Down-Hill Slope.

5.2 Type of Pavement

5.2.1 *Rigid Pavement*

Considering various aspects brought out in preceding paras, rigid pavement is not generally recommended for roads in hilly regions. In seismic areas, rigid pavement is liable to severe damages whereas flexible pavement, by its granular composition, can withstand effects of tremors better. Hence flexible pavement is normally provided on hill roads and is therefore dealt with in detail. However, provision for rigid pavement may be considered where site conditions, traffic etc. necessitate and permit like bus depot, toll plaza, passing lane, in front of habitation, at water fall location, hairpin bands, over culverts, causeway and bridges etc.

5.2.2 *Flexible Pavement*

A flexible pavement essentially consist of three functional layers such as sub-base, base and bituminous layers above sub-grade. A flexible pavement disperses load in a geometrical pattern **(Fig. 5.3).** Each lower layer has a lesser stress due to dispersion of load, hence, in principle, the highest quality material should be nearest to the load and weakest material farthest away. All granular and bitumen bound pavements are flexible. Essentially, in a flexible pavement, the strength and quality of material used may progressively increase from sub-grade to the top of the pavement, where the load of vehicles comes in contact with road surface.

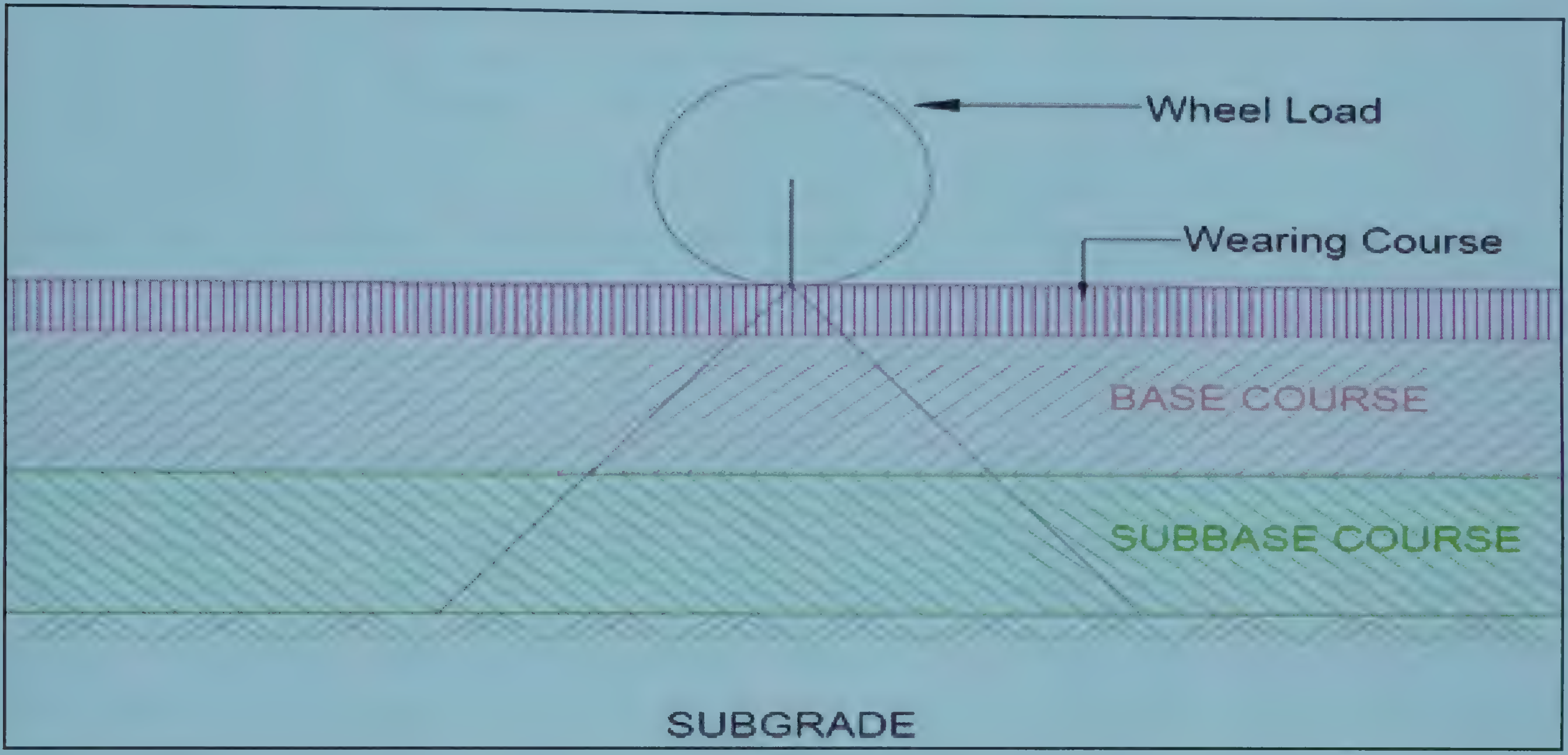


Fig. 5.3 Load Dispersal in Pavement

In a road the entire width on which construction activity takes place is defined as road bed which is the sub-grade. To make the road bed passable to traffic in all seasons/weather, a hard surface is laid. This surface may consist of sand, gravel, crushed rocks with binding materials. The binding material may be bitumen (VG), lime or cement. This hard surface laid on sub-grade is the pavement. The sub-grade soil is compacted or stabilized, as required, to ensure its desired strength and depending upon the CBR (effective) value of sub grade and traffic intensity the total thickness of different pavement layers is determined as specified in IRC:37. The specifications of subgrade, sub-base and base course layers shall conform to the specifications as laid down in the respective Clauses of MoRTH/MoRD

(a) **Sub-Grade:** The sub-grade which is natural soil brought to required profile and compacted to optimum density serves as foundation of the road structure and the entire load on the road is taken evenly by the sub-grade. Sub-grade is the top 50 cm of the road bed covering entire formation width of road. This sub-grade supports the road pavement.

- For design, the subgrade soil strength is normally assessed in terms of the California Bearing Ratio for use in the flexible pavement design method. The subgrade strength depends upon the type of soil, degree of compaction, worst moisture content and the climatic conditions that the subgrade would attain during the design life of the road.

- The conventional procedure for evaluating the sub-grade strength is by determining its laboratory CBR, an empirically determined index value representing the resistance to penetration of the subgrade soil. The subgrade soils in the hilly regions normally vary from hard rock to soft shale with intermediate type shaving gravel with different percentage of binder, silty gravels, silty clays, silty sands and boulders mixed with varying proportions of silty and clayey soils etc. Conventionally, the soil CBR is determined by soaking the soil for 4 days. However, it is observed that clayey soils with high plasticity do not attain saturation even after 4 days soaking. In view of the heavy and continuous rainfall in hilly regions, it is suggested that all expansive clays/silty expansive clay showing high to very high degree of swelling (as per IS: 1498, Table 8) shall be soaked in water for 7 days before determining CBR.

- The soaked CBRs on disturbed samples are conducted on soil fractions obtained after sieving the subgrade material through a 20mm sieve and compacting it at the Modified Proctor dry density and optimum moisture content. Allowance for larger material shall be made by replacing it by an equal amount of material which passes a 19-mm.IS Sieve but is retained on 4.75-mm IS Sieve.

- The various sub-grades materials have been grouped into various strength categories ad their typical CBR values (only for guidance. Exact value to be determined based on field samples) given in **Table 5.1.** For the purpose of pavement design as per IRC:37 the effective CBR of subgrade shall be minimum 5%.

Table 5.1 Type of subgrade material and CBR (Indicative)

Category	Type of Sub grade	Strength Designation (CBR etc. range)
1.	Rocky subgrade, conglomerates, slate	High strength – CBR not the criterion
2.	Gravel with binder soil less than 20% hard slate	Soaked CBR 8-15
3.	Gravel with binder soil more than 20% shale of medium hardness, silty sands	Soaked CBR 5-10
4.	Silty clays and soft shale	Soaked CBR 2-5

- In hilly regions, due to repeated freezing and thawing, water soluble salts tend to move up due to capillary action (Salt infestation of sub-grade). Besides leading to hardening of bitumen due to chemical action, salts, due to change in volume on freezing and thawing, break-up the pavement in cold regions. Wherever, slats concentrations in excess of 0.2% are met with, a capillary cut off in the form of a layer of coarse sand 225 mm shall be provided on subgrade to check the upward movement of the moisture from below. Addition of appropriate quantities of gypsum to form non-expansive calcium salts can also be used to correct the situation. For details of recommendations for road construction in salt infested areas reference may also be made to IRC:34 "Recommendations for Road Construction in Areas affected by Water Logging, Flooding and/or Salts Infestation".

- In case of sub grade CRB less than 2% a capping layer of 150 mm thickness of coarse material with minimum CRB of 10% may be provided over the sub-grade in addition to sub-grade requirement for 2% CBR.
- If the subgrade is fine sand or clay with plasticity index more than 15 and/or clay content more than 50%, a 100 mm insulating layer of screening or coarse sand should be laid on top of such subgrade, the gradation of material selected depending on whether it is intended to act as a drainage layer as well. Alternately, appropriate geo-synthetics performing functions of separation and drainage may be used over prepared sub-grade.
- If the road bed materials is expansive soil like black cotton soil, a non-expansive buffer layer should be placed over the same to act as subgrade. Alternatively, a blanket course of at least 225 mm thickness composed of course/medium sand or non-plastic moorum having plasticity index less than 5 should be provided on the expansive soil subgrade (as a sub-base in addition to sub-base required as per design) to serve as an effective intruslon barrier. This blanket should extend over the entire formation width.
- For the cut formation, which serves as a sub-grade shall be prepared as per the procedure given under para 5.1.2
- For the estimation of sub-grade CBR (effective), details given in IRC:37 shall be followed.

(b) **Sub-base:** This consists of a well-drained material placed on the sub-grade. The sub- base may be made up of granular materials like natural sand, moorum, gravel, laterite, kanker, brick metal, crushed stone, crushed slag or combination thereof or other materials like stabilized soil which remain static under saturated conditions. Soil aggregate mixes also are suitable for use in sub-base. The sub-base may be in more than one layer and in such *case* nomenclature as lower sub-base and upper sub-base may be used. The sub-base shall be provided on the entire formation width. Normally, the gradation of granular sub-base is provided as per MoRTH specifications, Table 401 "Grading for Granular Sub-base Materials" and the thickness of granular sub-base shall be designed as per details given in IRC: 37.

(c) **Base Course:** The base course consists of granular unbound or bound course placed above sub-base and transmits load and shear stress on pavement to sub-grade through sub-base. The base may be Wet-Mix Macadam (WMM), or any other equivalent granular construction material conforming MoRTH Specifications for Road and Bridge Works. The design thickness shall be as per details given in IRC- 37.

(d) **Wearing Course/Surface & Binder Course (Bituminous Layers):** This is the hard top crust of the pavement which comes in contact with the load. This consists of Wearing Course only or a Wearing Course over a binder course. The function of the wearing course is to with stand the abrasive and attractive stresses due to traffic, provide good riding surface and prevent ingress of moisture to the road bed. It also prevents the base course from ravelling. At times a binder Course is provided below a wearing course. It is a bitumen bound layer between granular base course and wearing course to give better load transmission and to act as a superior bound layer, reducing over-all thickness of unbound /cemented granular base as a whole. The binder course is provided on roads with higher traffic intensity. While wearing course may be Surface Dressing. Mix-Seal, Surfacing, Open Graded Premix Carpet, Semi-Dense Bitumen Concrete or Bituminous Concrete, binder course is generally either Bituminous Macadam or Dense Bituminous Macadam. Reference may be made of MoRTH Specifications for Road and Bridge Works for material specifications and IRC:37 for thickness design of the bituminous layers.

5.3 Factors Governing Design of Pavement

5.3.1 Design of Pavement requires considerations of wheel load of vehicles, traffic, climate, terrain, sub-grade condition etc. Methods of pavement design normally used in the plains based on quantitative and qualitative evaluation of sub-grade materials (soils etc.) for withstanding given conditions of traffic and climate also take advantage of the successful past practices and experience. This is equally applicable in the case of hill roads also duly considering aspects peculiar to hill areas as given in para 5.1.2.

5.3.2 The design procedure, as applicable to plains/rolling terrain, will apply to, hilly regions in lower altitudes, high altitudes which are not snow bound, valleys and high rainfall areas. The IRC: 37 “Guidelines for Design of Flexible Pavements” have generally been adopted in this manual However selection of specifications, composition of component layers, provision for drainage etc., have to be done to suit the special problems in such areas.

5.4 Traffic Growth Rate

5.4.1 For the purpose of structural design of pavement, the total no of commercial vehicles that are likely to ply on the road in the designed period are considered and is expressed is terms of MSA (Million Standard Axle) of cumulative number of equivalent standard load of 80KN. However, for purpose of deciding on the lane width of road/pavement, all kinds of traffic i.e., from Animal Drawn to heavy vehicles are considered and converted as per norms to equivalent Passenger Car Units (PCU). To obtain realistic estimate of design traffic, due consideration should be given to the existing traffic and anticipated in case of new construction, possible changes in road network, land use of the area served, the probable growth of traffic and design life.

5.4.2 The following guidelines be adopted for traffic estimation:

a) Initial average traffic for any road should be based on 7 days of 24 hours in peak season classified traffic counts. Which should also involve seasonal correction factor and Axle load survey and analysis, for determination of VDF.

b) On new roads traffic estimation is forecast on land use, development needs and traffic on adjacent routes in the area.

c) Traffic growth may be predicted on past trends.

d) In absence of accurate data for estimation of actual growth rate of commercial vehicles or when the estimated growth rate is less than 5%, a minimum growth rate of 5% shall be used for commercial vehicles for estimation of design traffic.

5.4.3 The procedure for traffic census as laid down in IRC: 9 “Traffic Census for Non-Urban Roads” and traffic growth estimation as laid down in IRC: 108 "Guidelines for Traffic Forecast on Highways" shall be followed;

5.5 Computation of Design Traffic: The design traffic in terms of the cumulative number of Standard axles to be carried out during the design period of the pavement shall be estimated as per details given in IRC: 37.

5.6 Design Period

5.6.1 The design period to be adopted for pavement design is the time span considered appropriate for the road pavement to function without major rehabilitation. The minimum design period of 20 years (excluding construction period) shall be adopted for the structural design of pavements for National Highways, State Highways and Urban Roads. For other categories of roads, a minimum design period of 15 years shall be adopted.

5.6.2 Very often it may not be possible to provide the ultimately needed full thickness of pavement right at the time of initial construction. In such cases stage construction techniques could be resorted to and those forms of construction chosen that could readily be strengthened as traffic increases. The initial construction stage period should not be less than 10 years. However, in case of pavements with cement treated bases & sub bases, stage construction is not allowed. For further details on stage construction IRC:37 shall be referred.

5.7 Carriageway and Lateral Distribution of Traffic

5.7.1 Several hill roads in the past have been designed as single lane and intermediate lane roads. However, it may be mentioned that road accidents and resulting fatalities is a major concern in India. The chances of head-on collision increase significantly on single lane and intermediate lane roads as traffic from both directions share the same path. Further, traffic congestion on such roads due to incidents (for. e.g. vehicle breakdown, road accidents, slow moving vehicles, etc.) is frequent and the resulting impact on the community and the environment is significant. The geometry of hill roads especially curves, steep grades, and restriction in sight distances aggravate road safety problems. Also, several hill roads provide connectivity to borders and sensitive areas, and are also through roads. On one side, traffic growth on many of these roads are significantly high and their strategic importance is also high. Safe and efficient road connectivity is also a pre-requisite for the economic development of hilly regions and most of these regions have limited rail connectivity. In many cases, widening of single lane roads to two lane standard is required even before the disturbances caused to terrain (for e.g. cutting of hills, vegetation, etc.) is absorbed by the nature. Considering all the above factors, it is recommended to develop new roads as at least two-lane width. Unless the roads terminate inside the village (i.e. not a through road) and region is unlikely to grow in the next 10 years.

5.7.2 A realistic assessment of distribution of commercial traffic by direction and by lane is necessary as it directly affects the total load application in the design traffic (Equivalent standard axle load application). For existing roads, it is necessary to carry out seven day-traffic volume studies to understand the present traffic variation and directional distribution. It may be noted that the observed traffic volume on such hill roads which is a function of the road condition is often restricted by the available limited capacity of the roads. This aspect need to be duly considered in the forecasting of traffic on hill roads. If in a particular situation a better estimate of the distribution of traffic between the carriage way lanes is available from traffic forecasting surveys, the same should be adopted and the design made based on the traffic in the most heavily trafficked lane. It is therefore first foremost recommended that assessment of the distribution must be carried on the basis of traffic forecasts. The following directional/lateral distribution may be assumed only under circumstances when traffic forecasts are not possible. The design, as evolved, will apply to the whole carriage way width;

a) Single-lane roads (3.75 m width): Traffic tends to be more channelized on single lane roads than on two-lane roads and to allow for this concentration of load, the design should be based on the total number (sum) of commercial vehicles per day in both directions

b) Intermediate width roads (5.5 m width): The design should be based on 75% of the total number of commercial vehicles per day in both directions.

c) Two lane single carriageway roads: The design should be based on 50% of the total number of commercial vehicles per day in both directions.

d) Four-lane single carriageway roads: The design should be 40% of the total number (sum) of commercial vehicles in both directions should be considered for design.

e) Dual carriageway roads: The design of dual two-lane carriageway roads should be based on 75% of the number of commercial vehicles in each direction.

5.7.3 The traffic in each direction may be assumed to be half the sum in both directions when the latter only is known. Where significant difference between the streams can occur, the condition in the more heavily trafficked lane should be considered for design.

5.8 Road Capacity and Pavement Width

5.8.1 Width of carriageway and therefore the pavement width will be arrived at based on the traffic census and/or design road capacity as given in IRC:52 (Guidelines for the Alignment Survey and Geometric Design of Hill Roads).

5.8.2 Tentative equivalency factors for conversion of different types of vehicles into equivalent Passenger Car Units (PCUs) based on their relative interference values are given in **Table 5.1** below. These factors are meant for open road sections and not for intersections.

Table 5.1 PCU Factors for Various Type of Vehicles on Rural Hill Roads

S. No.	Vehicle of Type	Equivalency Factor
	Fast Moving Vehicles	
1.	Motor Cycle or Scooter	0.50
2.	Passenger Car, Pick-up Van, Auto Rikshaw/Tempo,taxi, mini -LCV	1.0
3.	Agricultural Tractor without Trailer, Light Commercial Vehicle, Mini-Bus	1.50
4.	Truck or Bus.(2-Axel,3-Axel)	3.00
5.	Truck-trailer, Agricultural Tractor-trailer, Multi Vehicle (4 & above Axel)	4.50
	Slow Moving Vehicles	
6.	Cycle	0.50
7.	Cycle Rikshaw	2.00
8.	Others(Specify)	3.00
9.	Animal Drawn	6.00

5.9 Vehicle Damage Factor (VDF)

The vehicle damage factor, a multiplier for converting the number of commercial vehicles of different axle loads to the number of standard axle-load repetitions, takes into account the various influencing factors of traffic mix, type of transportation, type of commodities carried etc. The values of Vehicle Damage Factor (VDF) based on details as indicated in IRC:37 shall be taken for pavement design.

5.10 Climatic Conditions, Terrain Conditions and Other Special Problems

The design, specifications and selection of component materials suitably related to climate, terrain, topography and specific conditions obtainable in specific regions of hilly areas are dealt in the appropriate places in this chapter. The design of pavement for high rainfall, high altitudes and snowfall areas are dealt as under.

5.10.1 *Pavement Design for Heavy Rainfall Areas*

- In heavy rainfall areas provision of an effective network of line and cross drainage is necessary to ensure satisfactory performance of the pavement. The provisions as brought out in Chapter on drainage on drainage measures be followed properly.
- Though road pavement in such area is designed and provided in a normal manner but in areas where annual rainfall is higher than 300 cm the formation width on hill side may be surfaced up to line drains without leaving any gap between edge of pavement and drain. Suitable decision on this aspect may be taken by the executives depending upon the criticality of the area and budget provision.

- Dense bituminous mixes viz Bituminous Concrete (BC) at surface level and Dense Bituminous Macadam (DBM) at base/binder course be provided in such areas. Mastic Asphalt mix can also be used as an alternative surface course.

5.11 Pavement for Snow Fall, High Altitude/Snow Bound Areas

5.11.1 *Snow fall Areas in different Altitudes*

a) Snow fall occurs in certain areas at altitudes between 2500 m to 3000 m where rainfall also is medium. In such areas the snow fall is such that the same can be continuously cleared on occurrence. To quote examples of such places, the Western Himalayas in Jammu & Kashmir and Eastern Himalayas come under this, where rainfall also is medium to fairly high. In these areas winter snow clearance can be resorted to keep the road open throughout the year.

b) High altitude areas above 3000 m of the Great Himalayan ranges which are distinct snow belts where intensity and periodicity is so high that the snow is allowed to accumulate in winter months and road closed in winter. The snow clearance is undertaken in summer. Here the problems of avalanche, frost, icing, etc. are encountered.

The subject of snowfall, etc., are dealt in **Chapter 6 "Snow Clearance and Avalanche Treatment"**

5.11.2 *Pavement for Areas at Lower Altitude*

Pavement for areas subject to snow-fall at lower altitudes where continuous snow clearance can be done.

(i) In such areas the normal design of flexible pavement would be generally adequate with certain specific provisions. Certain important roads including National Highways in such areas in Western Sector of Himalayas have been performing successfully. While designing/providing pavement, the following should be considered:

  a) The specification for Wearing course consisting of thick dense carpets should be considered in preference to open-graded carpets.

  b) The entire formation width may be surfaced, as suggested for high rainfall area, leaving no gap between edge of pavement and drain/parapet. In any case shoulders should be hard shoulders.

  c) Since snow clearance will be done by heavy equipment, dense asphaltic/bituminous layers in wearing course and bituminous layers in base courses would be preferable.

  d) Geo-cell and Geo grids may also be used at sub-base and level with granular material (to improve the elastic modulus of granular layer) with bituminous base and surfacing suitably where CBR value of sub-grade is low and availability of aggregates is a concern.

(ii) Maintenance and drainage of roads in such areas should be given full attention. Periodicity of renewal of surfacing may be more frequent than guidelines, as required by ground conditions.

5.11.3 *Pavement for High Altitudes (above 3000 m) that remain Snow Bound in winter*

In high altitude areas which are subjected to heavy snowfall, sub-zero temperature, frost action, snow drifts and avalanche activities, design and construction of pavement require special consideration. The performance of conventional type of flexible pavements, comprising viz. GSB, WBM etc. may not be found satisfactory due to factors like:

a) Frost heaving and thawing action.
b) Intensive snow and avalanche activity.
c) Icing problems
d) Damage by movement of tracked vehicles during snow clearance operations.
e) Loss of ductility of bitumen due to sub-zero temperatures.
f) Blocking of drainage system
g) Glacier and avalanche movements on the road.

The above result in excessive maintenance requirement and even destruction of pavement and allied structures. Roads in high altitude areas should be designed to retain their stability and service ability in spite of yearly relentless cycle of freezing and thawing and occurrence of avalanches. Bitumen of grade VG-10 or VG-20 is recommended for BC/DBM but has to be done with extreme care i.e., when weather is conducive, with base of W.M.M and sub-base of G.S.B. as per MORT&H Specification. In Avalanche areas of short distances stone bed could be preferred.

5.11.4 *Climatic Factors*

This is the singular most important factor which influences the design of road in high altitude areas. Factors like snow fall Intensity, temperature, avalanche, snow drift, Icing and frost action must be considered along with traffic Intensity, Its growth, and axle load and design life. The subject of climatic factors except frost and its effects have been brought out in Chapter-6 and traffic related issues in this chapter itself which may be referred.

5.11.4.1 Frost action (Frost Heaving and Thawing)

Frost can be defined as process of freezing or deposit/covering of minute ice crystals formed from frozen water vapour. Due to the exposure of the area to sub-zero temperatures for months together the soil temperature falls below the freezing point. Due to the fall in temperature, moisture at subgrade level freezes and results in formation of ice crystals. When water freezes, it expands about 9 per cent of its original volume and is known as frost heave.

In some cases water becomes super cold and remains in liquid state at temperature well below freezing, point. The super cold water and ice crystals have strong affinity, with a result the water is drawn to ice crystals that are initially formed and thus continue to grow until ice lenses begin to form. The ice lenses in turn grow until frost heaving results. **Fig. 5.4** Illustrates ice-lens formation and frozen soil strata.

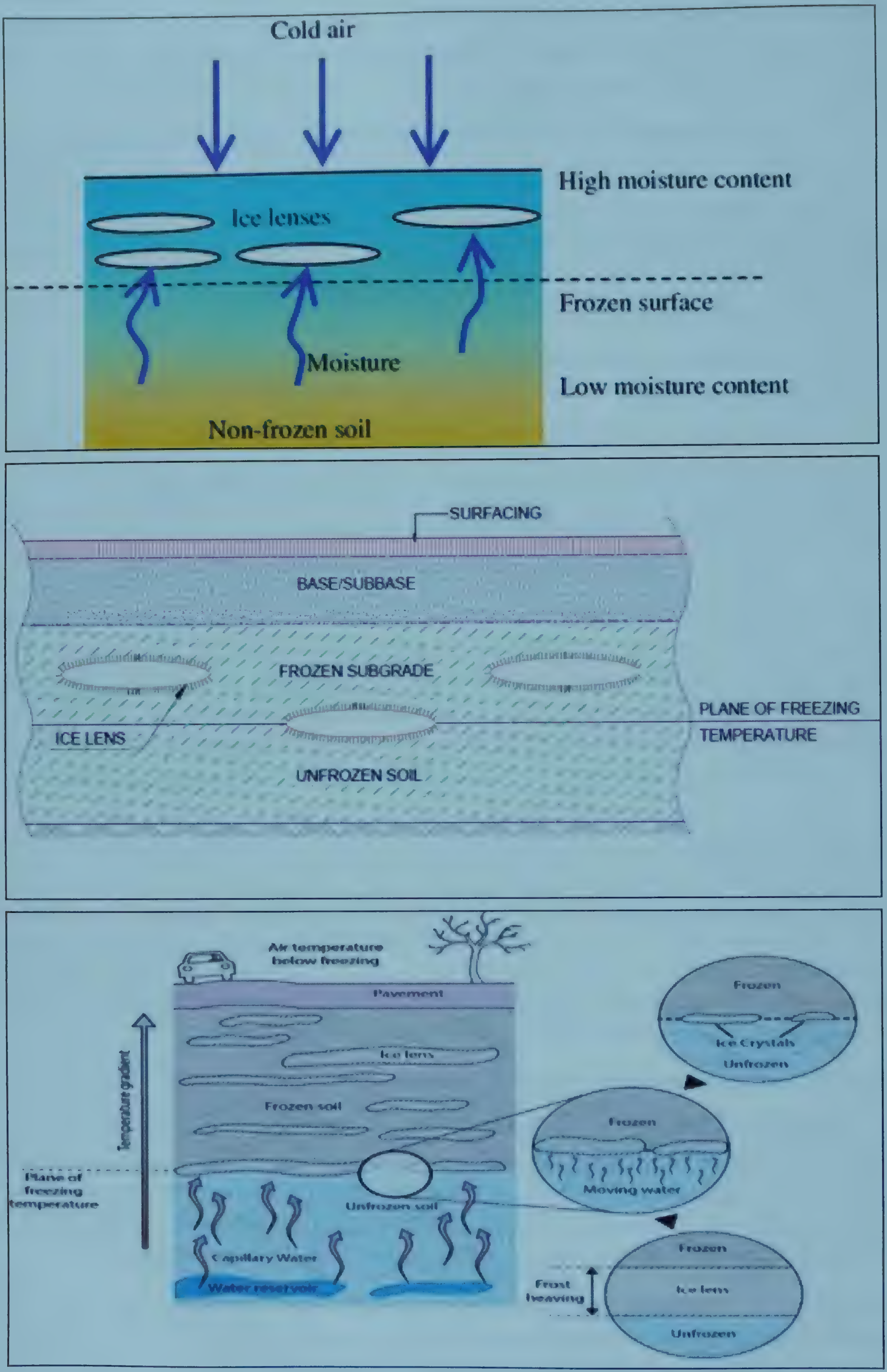

Cold air
High moisture content
Ice lenses
Frozen surface
Moisture
Low moisture content
Non-frozen soil
SURFACING
BASE/SUBBASE
FROZEN SUBGRADE
PLANE OF FREEZING
TEMPERATURE
ICE LENS
UNFROZEN SOIL
Air temperature
below freezing
Pavement
Ice lens
Frozen soil
Temperature gradient
Plane of
freezing
temperature
Unfrozen soil
Capillary Water
Water reservoir
Frozen
Ice Crystals
Unfrozen
Frozen
Moving water
Frozen
Frost
heaving
Ice lens
Unfrozen

Fig. 5.4 Frozen Soil and Ice Lens

After the winter when atmospheric temperature increases above the freezing point, the melting of ice lenses start. As the thermal conductivity of frozen soil is greater than unfrozen soil, the melting of ice lenses releases an excess of water within the soil, with a corresponding reduction in load supporting capacity of the subgrade and consequently pavement as a whole. Further, since restriction of vertical drainage is a characteristic of frozen ground in seasonal frost areas, the excess water released. By melting of ice lenses cannot drain downward through underneath impervious frozen sub-soil. The water, therefore, tends to ooze upward and saturate subgrade/ sub- base/base course, resulting in very unfavorable conditions in which not only the subgrade is in a weakened condition, but the pavement itself may be supported in part by water under traffic loading. Loss of subgrade supporting capacity can be considerable in magnitude (almost 50%) and may exists for relatively long periods of time after thawing has taken place. The weakening of sub-grade and pavement gets aggravated further during snow melting period because of wide variation in day and night temperatures. During day time, temperature rises sometime up to 25 degrees and in night it falls even below zero degrees. Due to fall in temperature below freezing point during night, alternate thawing and freezing take place. Each time the soil freezes a loss of density results. This, in turn, results in higher potential for moisture absorption. After several cycles of freezing and thawing, a large portion of the subgrade supporting capacity is lost.

5.11.4.2 Low Atmospheric Temperature

In high altitude areas, flexible pavements become brittle and least ductile during the period of subzero temperature when the greatest shrinkage tendency and heave occur. Brittleness of the pavement results in cracking of pavement surface. Cracks at pavement surface provide means for ingress of moisture into the base/sub-base/sub-grade. This offers a point where raveling starts and where freezing of moisture in and immediately below the cracks add to further widen and intensify the cracks, as a result of which the life of pavement is affected adversely.

5.11.4.3 Frost Susceptibility of Soil

From the point of view of pavement design and construction, the need is for a simple set of criteria to distinguish whether a given soil is frost susceptible or not. Such criteria, in empirical form, incorporating the principles of freezing of soils and formation of ice lenses has-been evolved by Casagrande essentially based on grain size to serve as a, useful guide. Casagrande concluded that:

a) Well-graded soil with 3 per cent or more soil particles less than 0.02 mm in size are highly frost susceptible.

b) Uniformly graded soils with 10 per cent or more particles less than 0.02 mm size are frost susceptible.

Elaborating the above system, soils have been divided into 4 groups F_1 to F_4 (by US Corps of Engineers) as in **Table 5.2** with increasing frost - heave potential as well as increasing loss of strength on thaw.

Table 5.2 Grouping of Soils Based on Frost Susceptibility

Sl. No.	Group	Designation	Characteristics
1.	F_1	Gravel soils containing between 3 and 20 per cent finer than 0.02 mm by weight	Least frost susceptible and least thaw weakening
2.	F_2	Sands containing between 3 and 15 per cent finer than 0.02 mm by weight	Increased frost- susceptibility and thaw weakening
3.	F_3	(a.) Gravel soils containing more than 20 per cent finer than 0.02 mm by weight	Frost susceptible and high thaw weakening
		(b.) Sands, except fine silty sands containing more than 15 per cent finer than 0.02 mm by weight	
		(c.) Clays with plasticity indices more than 12	
		(d.) Varved clays with uniform subgrade conditions	
4.	F_4	(a.) All silts including silty clays.	Frost susceptible and high thaw weakening
		(b.) Fine silty sands containing more than 15 per cent finer than 0.02 mm by weight	
		(c.) Lean clays with plasticity index less than 12	
		(d.) Varved clays with non-uniform subgrade conditions	

It may be surmised from above that while gravels, clean sands and highly plastic clays are not frost susceptible, silty sands, silts and lean clays are frost susceptible.

As regards adoption for design, while the above may be used, it would be desirable to study subgrades met on roads and update frost susceptibility criteria in the environments existing.

5.11.5 *Pavement Design for Protection against Frost Action*

For the areas which are affected by frost action two different concepts are available for design of pavements. The concepts are, control of surface deformation by provision of sufficient pavement thickness to reduce frost penetration and design for reduced subgrade strength during the frost-melt period. Both methods of design are explained below.

a) Limited Subgrade Frost Penetration

In this method, sufficient thickness of non-frost susceptible material is used so that only limited, tolerable penetration of freezing temperature into the frost-susceptible subgrade occurs. By this means, both pavement heave and subgrade weakening are reduced sufficiently in amount as well as frequency of occurrence and duration so that their effects may be neglected. Depth of frost penetration can be worked out from the conditions developed by Aldrich as per the modified Berggren's formula given as under:

$$= A\frac{\sqrt{48KF}}{L}$$

Where

Z = Depth of frost penetration

K = Thermal conductivity (which depends upon density of soil and moisture content) L = Volumetric heat of latent fusion

F = Air freezing index; degree - days

A = A dimensionless coefficient depending upon fusion parameter and thermal radiation

A number of charts have been developed by US Corps of Engineers based on field studies and research to arrive at depth of frost penetration in above equation. But these may not be directly applied to our conditions unless data on our situation is evolved by expert and research bodies.

b) Reduction in Subgrade Strength

This design approach is based on the reduced supporting capacity of the subgrade due to the thawing i.e. frost melting. A number of charts have been developed by US Corps of Engineers to work out the reduced subgrade strength and thickness of pavement required. But these cannot be readily extended to our conditions.

Both systems of assessing frost affected subgrade given in (a)&(b) above may be taken as for information. If necessary, study of sites by expert agencies in the field and site investigation will have to be done. However, an empirical method based on experience in field and performance of pavement in such areas are given in next para onwards.

5.11.6 *Pavement Composition and Layer Arrangement*

Based on experience on the design and performance of various types of pavements provided in such areas (in consultation with research bodies on the subject also), the following aspects emerge:

a) The design will have to be related to the actual depth of frost penetration and severity of frost.

b) Freezing conditions could develop within the pavement structure if water had a chance to ingress from above and hence has to be avoided.

c) Depth of construction (Pavement) should not be less than depth of front-penetration and should compose of non-frost susceptible materials. In any case the thickness should not be less than 45 cm. However, for details of recommendation for construction of rural roads, IRC:SP:20 “Rural Roads Manual” and IRC:SP:72 “Guidelines for the Design of Flexible Pavements for Low Volume Rural Roads” shall be referred.

d) Structurally strong courser like BM/DBM as against conventional granular bases like WBM or WMM will be more suitable especially if it is considered that heavy machinery and equipment are to use the road for snow clearance.

e) Crushed stone base, which is a better non-frost susceptible medium will be more appropriate as it is free draining also. It may extend over full formation width.

f) Alternate designs that are not flexible may also be considered.

5.11.7 *Alternate Specifications*

The various alternate specifications that may be adopted are as under for heavy snow accumulation/avalanches sites requiring clearance by heavy mechanical equipment:

5.11.7.1 Flexible Pavement

This may consist of a layer of Dense Bituminous Carpet, over Dense Bituminous Macadam on a Crushed Stone Base Laid on Non-frost susceptible sub-base. The suggested thickness is as under: **(Fig. 5.5)**

i) Non-frost susceptible sub-base (GSB) - 300 mm

ii) Crushed Stone Base (WMM) - 150 mm

iii) DBM - 75 mm

iv) Asphaltic Concrete (AC/BC) - 40 mm

565 mm

Note:

(i) If CBR values require higher thickness, the same may be made up by increased sub-base thickness

(ii) If conditions warrant only lesser thickness, the thickness may be restricted to not less than 450 mm by reducing sub-base thickness.

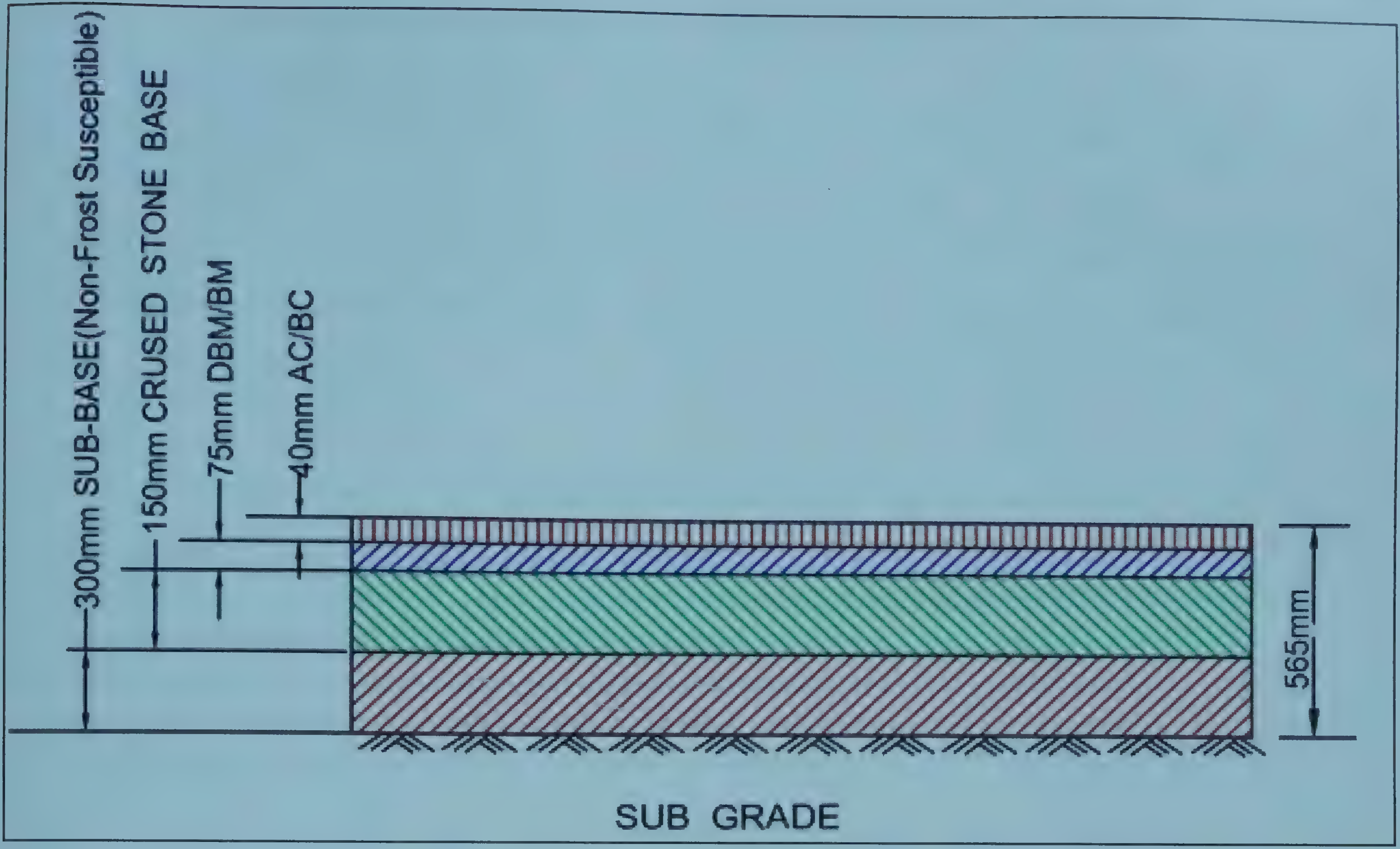


Fig. 5.5 Flexible Pavement in High Altitude/Snow Bound Area

(a) Specifications for Non-Frost Susceptible (NFS) Sub-base Course

Non-Frost Susceptible (NFS) Sub-base Course shall comprise of crushed aggregates/ crushed gravel with not more than 5 per cent of material finer than 75-micron sieve (wet Sieving), plasticity index not more than 6 and liquid limit not more than 25 per cent. When compacted to 98 per cent of maximum dry density (as per IS 2720 Part 8), the CBR value should not be less than 30 per cent. The material shall be free from organic or other deleterious matter (like clay balls, etc.) and water absorption as per IS 2720 Part 3 should be less than 2 per cent. Aggregate impact value determined as per IS 2386 (Part 4) should be less than 40 per cent. In addition, Non-Frost Susceptible (NFS) Sub-base Course material shall satisfy the Grading of **Table 5.3** below.

Table 5.3 Gradation of Non-Frost Susceptible (NFS) Sub-base Course

IS Sieve Designation	Percentage by Weight Passing the Sieve
75 mm	100
26.50 mm	55 - 75
4.75 mm	10 - 30
75 micron	< 5

The quality control tests during construction shall be carried out as per frequencies given in **Table 5.4** below.

Table 5.4 Quality Control Tests and their Minimum Frequency

Test	Frequency (Minimum)
Gradation	One test per 400 cubic metres
Atterberg Limits	One test per 400 cubic metres
Moisture Content Prior to Compaction	One test per 400 cubic metres
Density of Compacted Layer	One test per 1000 square metres
Deleterious Constituents	As Required
CBR	As Required

(b) Specifications for Non-Frost Susceptible (NFS) Base Course

The material shall be obtained from crushed hard rock free from any organic or other deleterious matter (like clay balls, etc). The material shall be of such nature that it can be compacted readily under watering and rolling to form a firm, stable base. Non-Frost Susceptible (NFS) Base Course shall be conforming to grading given in **Table 5.5**. The Physical requirements of Course Aggregates for Non-Frost Susceptible (NFS) Base Course is given in **Table 5.6**

Table 5.5 Gradation of Non-Frost Susceptible (NFS) Base Course

IS Sieve Designation	Percentage by Weight Passing the Sieve
45 mm	100
22.40 mm	90 - 100
5.60 mm	35 - 55
710 micron	10 - 30
90 micron	2 - 5

Table 5.6 Physical Requirements of Course Aggregates for Non-Frost Susceptible (NFS) Base Course

Test	Test Method	Requirements
Los Angeles Abrasion Value Or Aggregate Impact Value	IS 2386 (Part 4) IS 2386 (Part 4)	40% Maximum 30% Maximum
Combined Flakiness and Elongation Index	IS 2386 (Part 1)	35% Maximum
Water Absorption	IS 2386 (Part 3)	2% Maximum
Liquid Limit of Material Passing 425 Microns	IS 2720 (Part 5)	25% Maximum
Plastic Limit of Material Passing 425 Microns	IS 2720 (Part 5)	5% Maximum

5.11.7.2 Stone Set Pavement

This is a semi-rigid type of pavement. The stone is set over a layer of lean cement concrete (1:4:8) and crushed stone base. The sub-base should be non-frost susceptible material. **Fig. 5.6** illustrates arrangement. The suggested arrangement is as under:-

(i)	Non-frost Susceptible Sub-base (GSB)	- 300 mm
(ii)	Crushed Stone Base (CSB) (WMM)	- 150 mm
(iii)	PCC 1:4:8	- 150 mm
(iv)	Stone Set	- 150 mm

Note:

(i) *The thickness may be reduced up to 450 mm as per ground condition.*

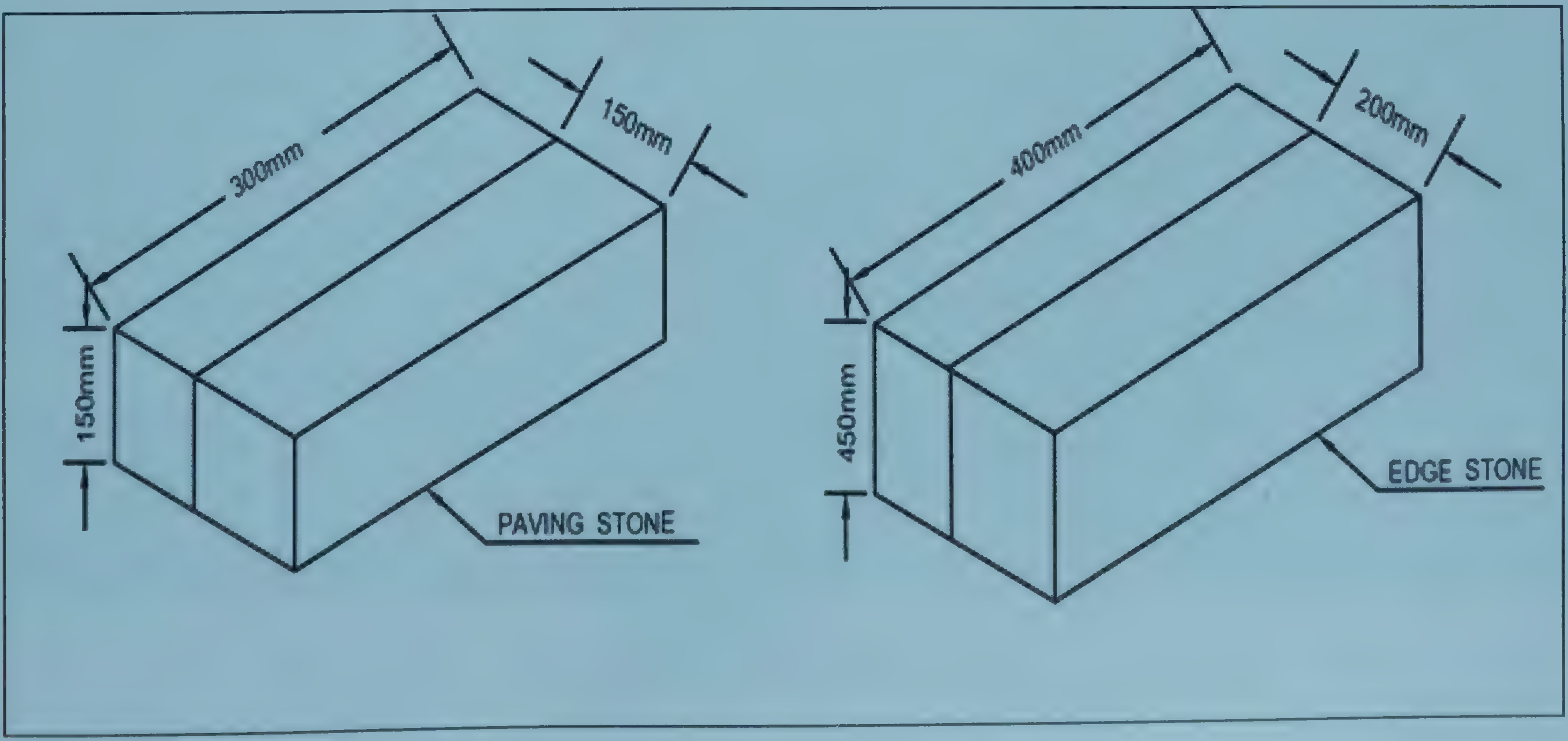
(ii) *Specification for the work is given below:*

"Stone used shall be of the best quality, locally available granite or other variety of igneous origin rock. If in a particular locality the origin of all stones is metamorphic the stone of the variety may also be used provided it is equal to granite in toughness and uniformity of texture. Sedimentary stone shall in no case be used.

Stone sets shall be rectangular in shape, 250 mm to 300 mm long, 150 mm to 200 mm wide and 150 mm deep, with tolerance plus or minus 12 mm. Stone sets used in any one area shall be of uniform size. They shall be hammer dressed on top to the extent that maximum depression of the dressed surface from a straight edge applied across any part of the surface for testing, does not exceed 20 mm. The dressing on the sides shall be similarly carried out, so as to obtain a mortar joint not exceeding 20 mm in width. They shall be set on the base concrete over a bedding layer of cement mortar (1:3) 20 mm thick, with joints not exceeding 20 mm, in width. The joints shall be grouted with cement mortar 1:2 with an admixture of metallic hardener such as ironite, hardonate or equal and approved variety, in the proportions as recommended by the manufacturers and joints struck off as work proceeds.

Stone set shall be laid in sections not exceeding 12 m long, in herring-bone pattern, separated by two rows of stone sets laid along the width of the road, with longitudinal axis of the stone sets parallel to the length of the road.

Edge stones shall be 350 mm to 400 mm long. 150 mm to 200 mm wide and depth not less than 450 mm laid with their longitudinal axis parallel to the length of the road."



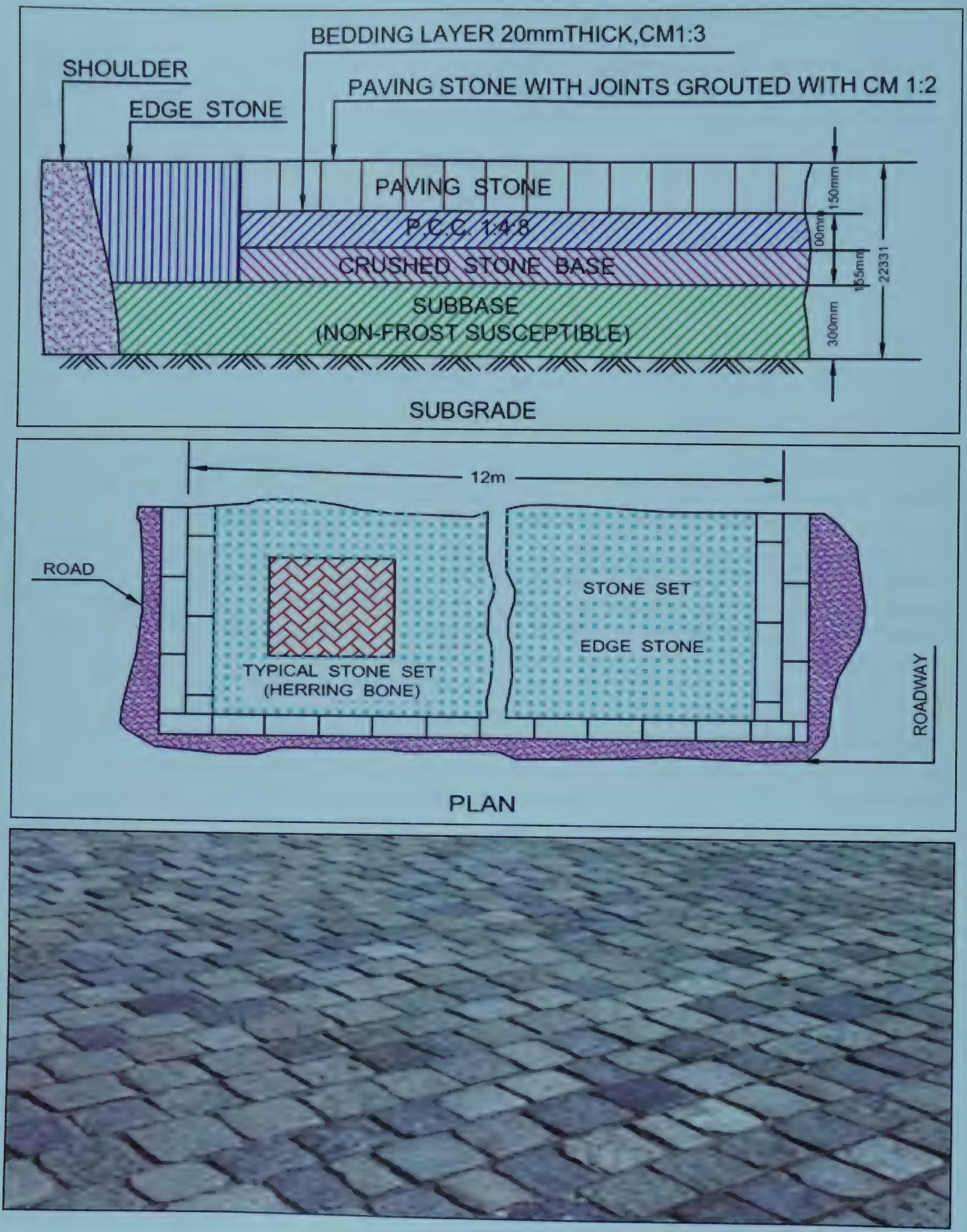

BEDDING LAYER 20mmTHICK,CM1:3
SHOULDER
PAVING STONE WITH JOINTS GROUTED WITH CM 1:2
EDGE STONE
PAVING STONE
P.C.C. 1:4:8
CRUSHED STONE BASE
SUBBASE
(NON-FROST SUSCEPTIBLE)
150mm
00mm
55mm
300mm
22331
SUBGRADE
12m
ROAD
TYPICAL STONE SET
(HERRING BONE)
STONE SET
EDGE STONE
ROADWAY
PLAN

Fig. 5.6 Stone Set Pavement

5.11.7.3 Precast Concrete Block Pavement (IRC:SP:63 and IS 15658)

Where construction time is limited and road is to be kept open during the construction stage, small size high density precast concrete blocks laid on sand over crushed stone base and non-frost susceptible sub-base is suitable, **Fig. 5.7** illustrates arrangement. The suggested arrangement is as under:

i) Non-frost Susceptible Sub-base (GSB) - 300 mm
ii) Crushed Stone Base (CSB) (WMM) - 150 mm
iii) Sand Layer - 30 mm
iv) PCC Blocks (M-30) - 200 mm

Note:

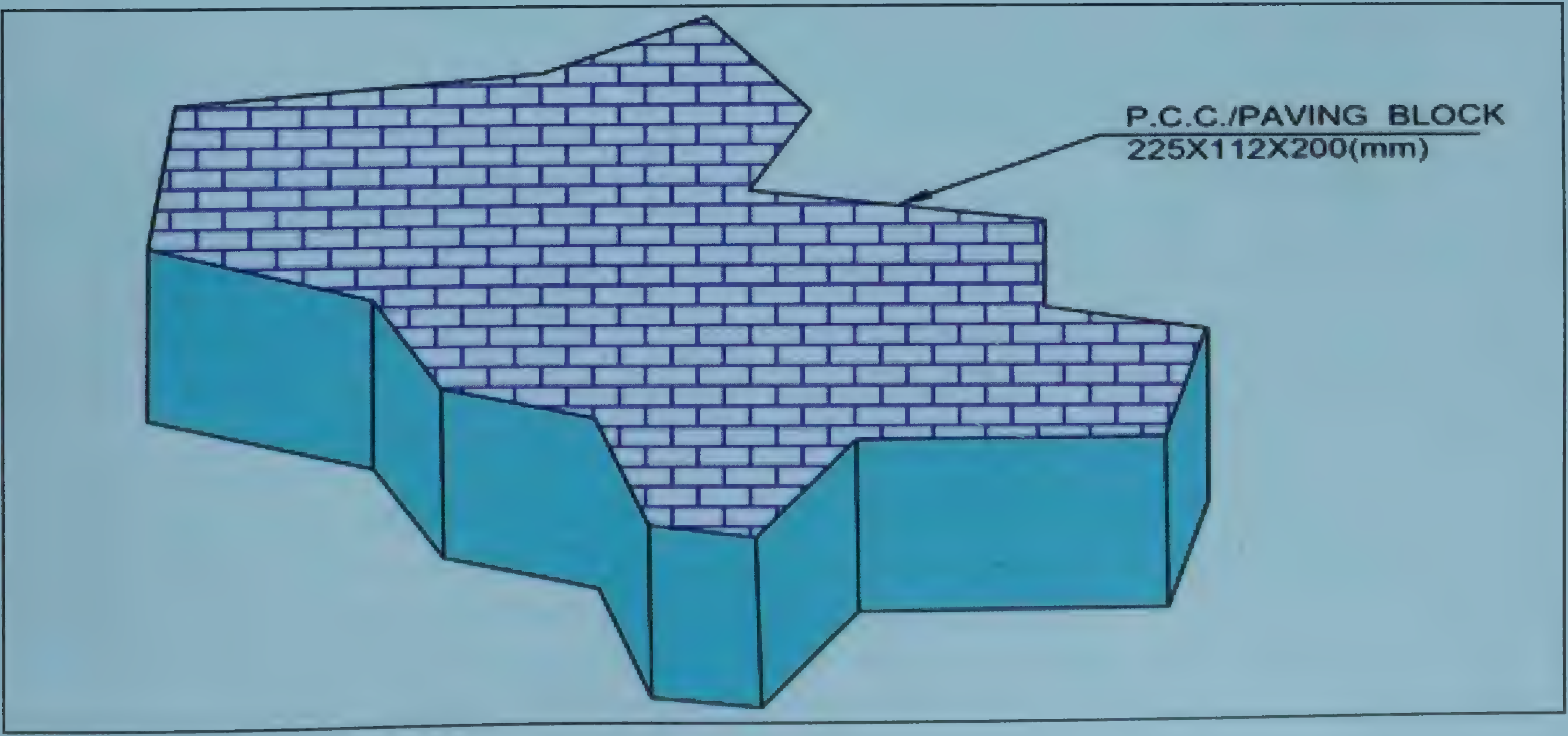
(i) The thickness may be reduced up to 450 mm as per ground conditions as in

(a) above.

(ii) Specification for the work is given below:

"The blocks of size 225 mm length, 112 mm width and 120 - 200 mm height are recommended as shown in ***Fig. 5.7.*** *To ensure adequate durability under the combined action of repeated freezing, thawing and snow clearance, the blocks should have high compressive strength, not less than 500 kg/cm sq. Cement used should be high strength ordinary Portland cement conforming to IS :8112-1989. Coarse aggregates should conform to IS: 383-1970 with size not exceeding 20 mm.*

Precast edge restraints are of prime importance to this type of pavement. The edge restraints prevent the blocks from migrating outwards, joints opening and interlocking being destroyed. Precast stones are laid in advance to provide edge restraint. Precast rectangular blocks of 200 mm -230 mm depth should be used for this depending on thickness.



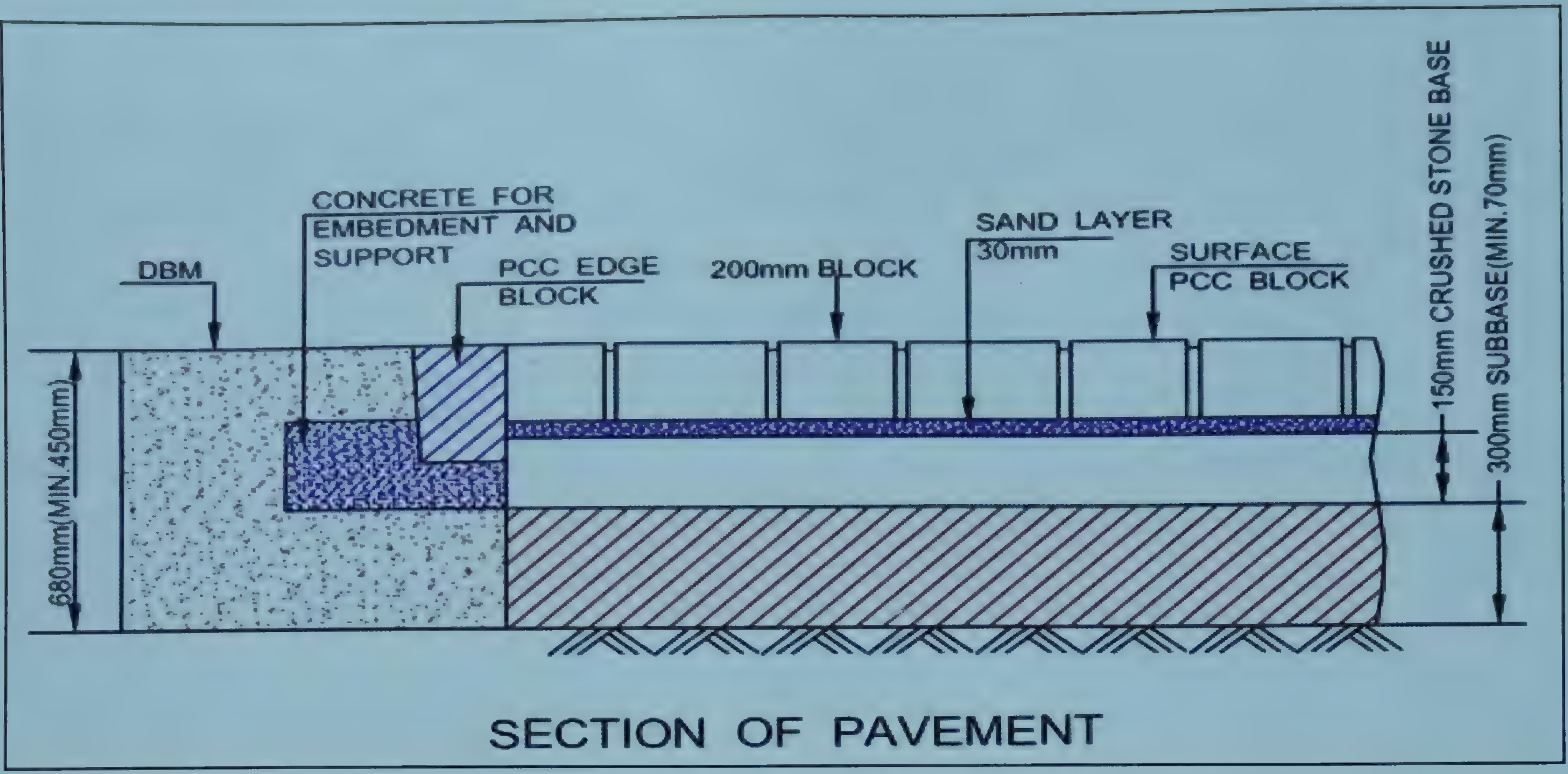
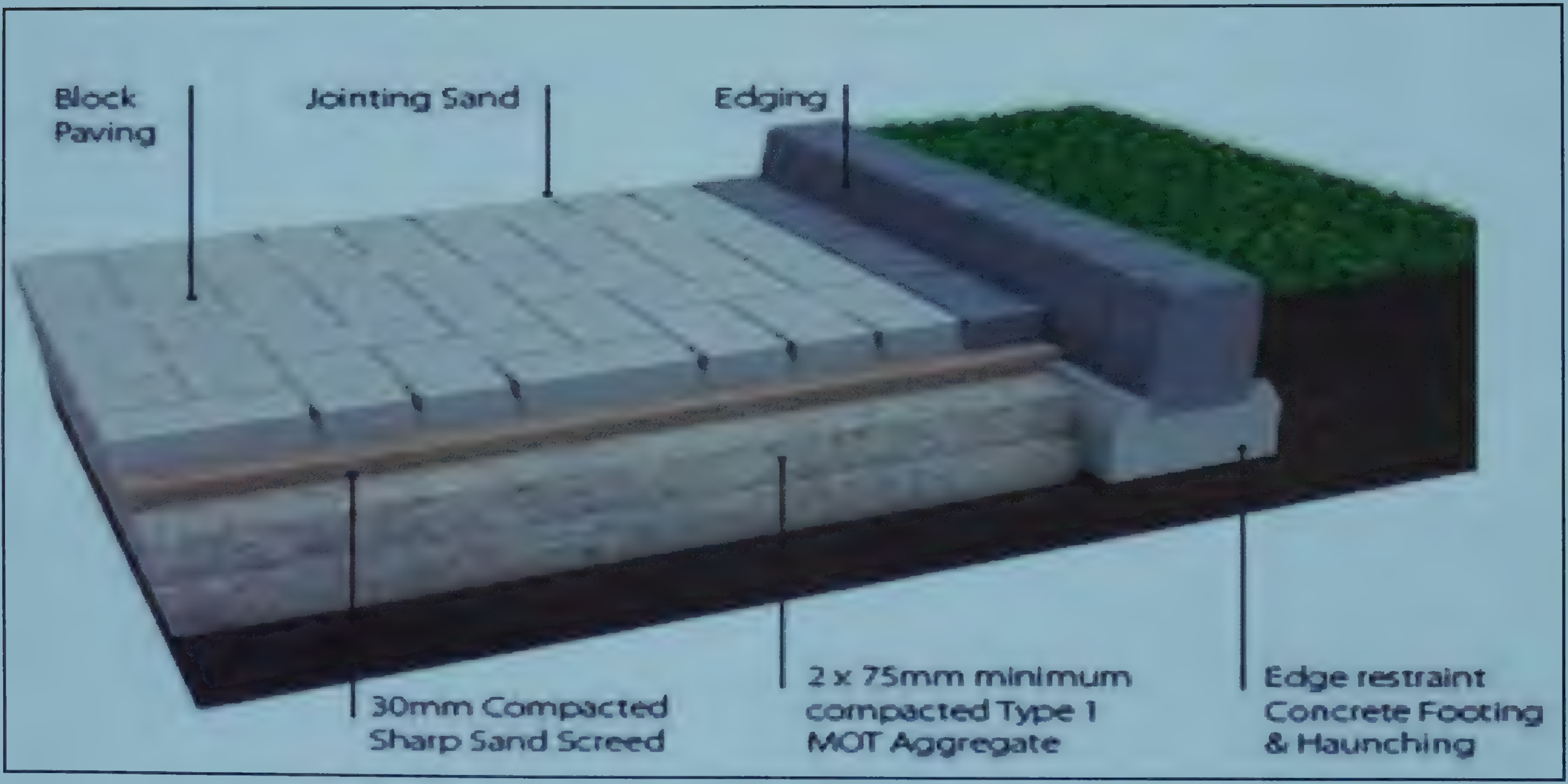

CONCRETE FOR EMBEDMENT AND SUPPORT
DBM
PCC EDGE BLOCK
200mm BLOCK
SAND LAYER 30mm
SURFACE PCC BLOCK
150mm CRUSHED STONE BASE
300mm SUBBASE(MIN.70mm)
680mm(MIN.450mm)
SECTION OF PAVEMENT

Fig. 5.7 P.C.C. Block Pavement


Block Paving
Jointing Sand
Edging
30mm Compacted Sharp Sand Screed
2 x 75mm minimum compacted Type 1 MOT Aggregate
Edge restraint Concrete Footing & Haunching

The blocks are laid manually in self-repeating herring bone pattern over full width in one operation. The surface of the block is vibrated using plate vibrator. After the vibrations, the sand is brushed over the blocks to fill the joints using a plate vibrator. Required number of vibratory passes is best determined by field trials."

5.11.7.4 Rigid Pavement

Rigid pavement is not generally recommended for roads in the hilly regions due to its high initial cost, practical construction problems, unstable areas, due to high temperature fluctuations and maintenance problem because of frost and snow precipitation. Cement concrete (reinforced/ unreinforced) is generally used on the hill roads at the places of causeways, bridges, culverts, tunnels, hairpin bends and also at the locations where special requirements call for this type.

Because of severe cold climatic conditions, the concrete paving slabs are subjected to frost action and freeze- thaw conditions. Thus under such conditions, the maintenance of the special concrete structures poses special problems such as scaling and slipperiness, spalling of joints and cracking etc. For the design of concrete pavements, reference may be made to IRC:58, IRC:15 & IRC:SP:62 whereas for their construction, Clause 602 of MORTH Specifications for Road & Bridge Works and other relevant IRC and BS Codes may be followed.

5.11.7.5 Composite Pavement

Composite design i.e. a combination of flexible and rigid pavement (called semi- rigid) is also not normally suitable for hill areas. However, for high altitude areas that are prone to avalanche activity and remains snow bound in winter, a combined type of pavement i.e. stone-set and PCC block paved on PCC base has been suggested in para 5.11.3 & 5.11.4 to overcome the frost effect problems as a specific method suitable for such areas.

Semi-rigid materials such as lean cement concrete have not been suggested for hill areas for same reasons for which rigid pavement is considered not suitable.

5.12 Pavement Drainage

As brought out in this manual repeatedly, drainage is the most important aspect for stability of a hill road. Pavement drainage is highly crucial for effective performance. These have been dealt with in Chapter 2 “Drainage & Cross-Drainage” and Chapter 6 “Snow Clearance and Avalanche Treatment” also as well as touched upon in other chapters. However, considering importance of the subject, certain aspects specifically related to pavement are reiterated.

The performance of a pavement in hill areas can be seriously affected if adequate drainage measures to prevent accumulation of moisture in the pavement structure are not taken. Some specific additional points related to pavement drainage and composition are given below:-

a) When the traditional granular construction is provided on a relatively low permeability subgrade, the granular sub-base should be extended over the entire formation width in order to drain the pavement structural section. **Fig. 5.8** depicts the arrangement.

b) Drainage of the pavement structural section can be greatly improved by providing a high permeability drainage layer (open graded material) which can be substituted on a centimetre for centimetre basis for the granular sub-base. Aggregates meeting the following criteria are regarded as very good drainage materials:

$$D_{85} < 4D_{15}$$

$$D_2 > \text{ or } = 2.5 \text{ mm}$$

D_{85} means the size of the sieve that allows 85 per cent by weight of the material to pass through it. Similar is the meaning of D_{15} and D_2. The drainage layer when placed on soft erodible soils should be underlain by a layer of filter material to prevent the intrusion of soil fines into the drainage layer. **Fig. 5.9** depicts this arrangement. Synthetic material like non-woven geo-fabric can also be used in place of graded filter material.

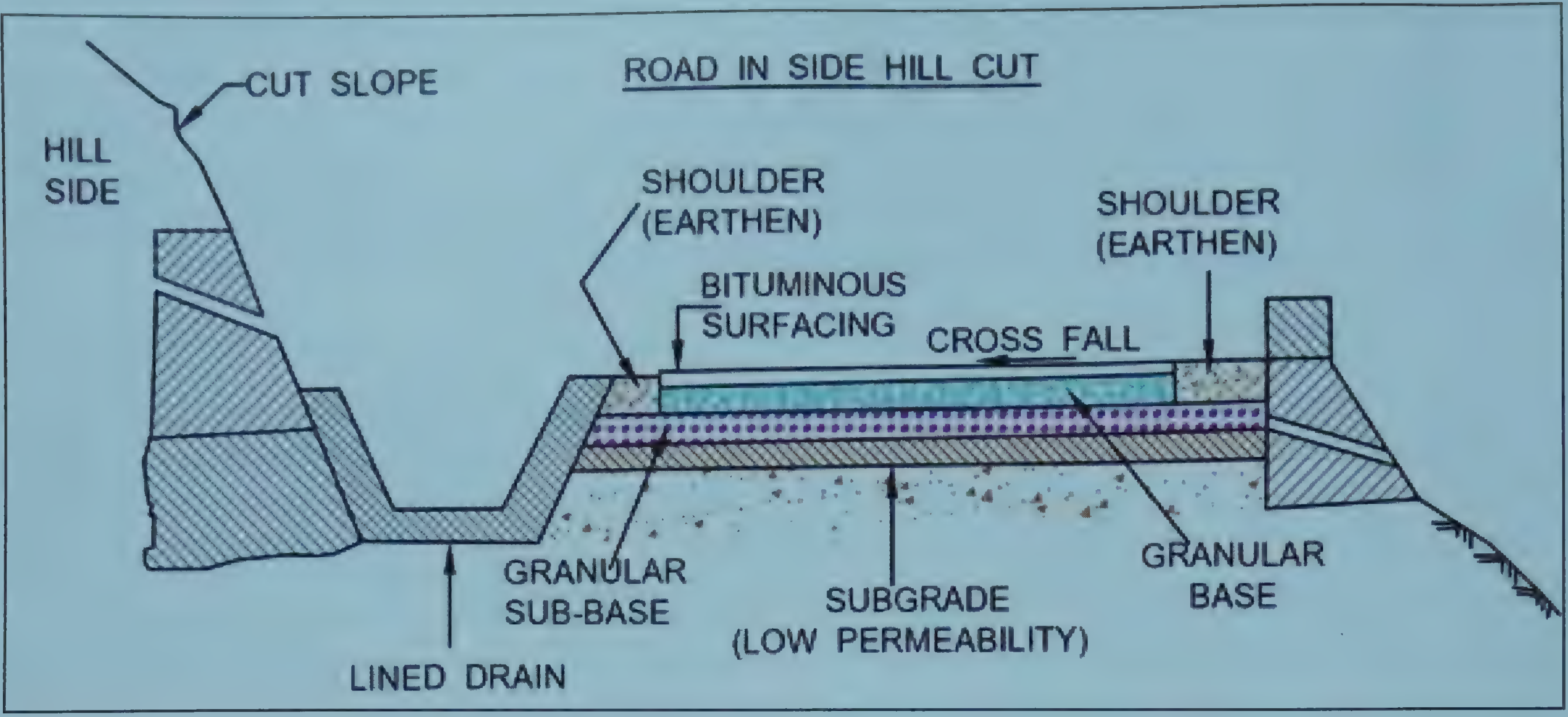

ROAD IN SIDE HILL CUT
CUT SLOPE
HILL SIDE
SHOULDER (EARTHEN)
SHOULDER (EARTHEN)
BITUMINOUS SURFACING
CROSS FALL
GRANULAR SUB-BASE
SUBGRADE (LOW PERMEABILITY)
GRANULAR BASE
LINED DRAIN

Fig. 5.8 Drainage by Extended Sub-Base

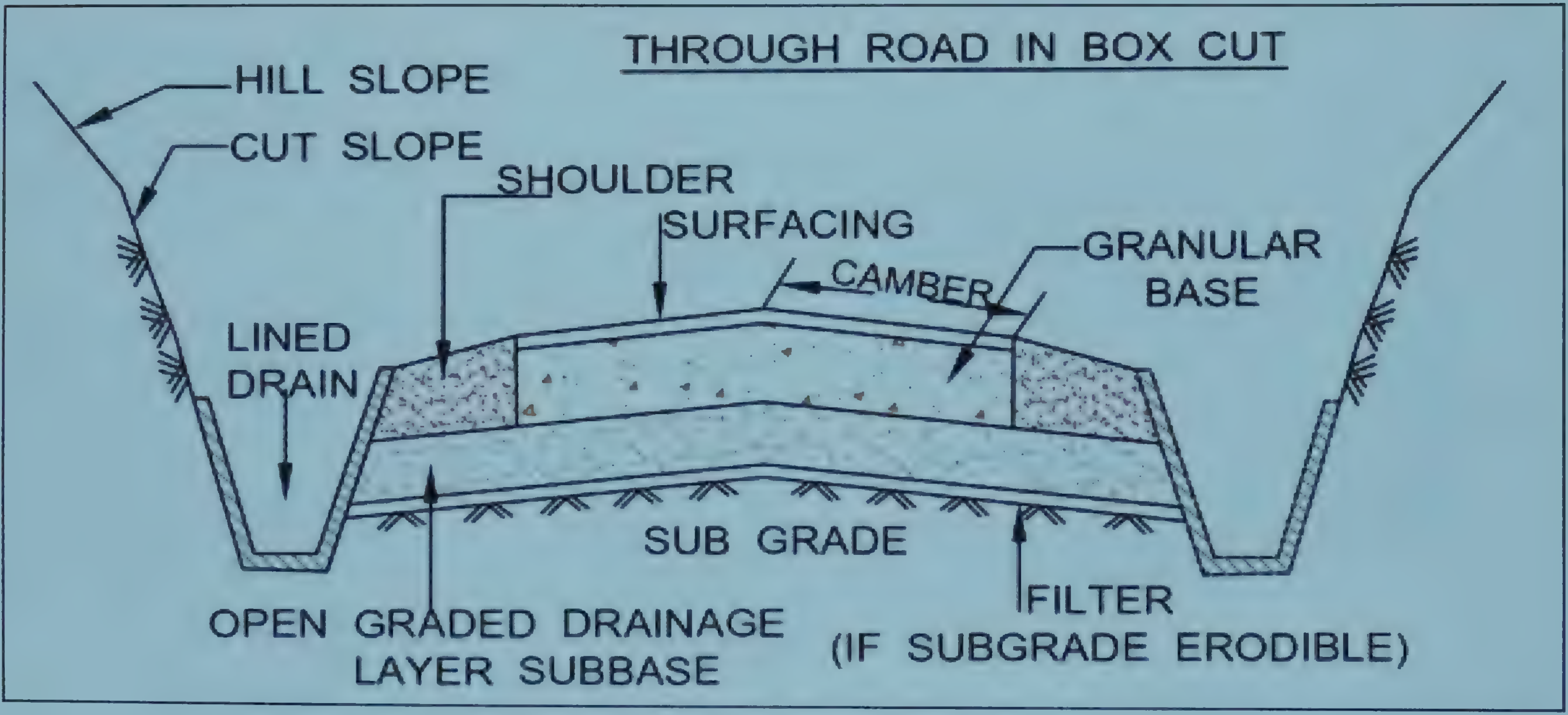

THROUGH ROAD IN BOX CUT
HILL SLOPE
CUT SLOPE
SHOULDER
SURFACING
CAMBER
GRANULAR BASE
LINED DRAIN
SUB GRADE
OPEN GRADED DRAINAGE LAYER SUBBASE
FILTER (IF SUBGRADE ERODIBLE)

Fig. 5.9 Drainage by Open-Graded Sub-Base

c) Where large inflows are to be taken care of, an adequately designed sub-surface drainage system consisting of an open graded drainage layer with collector and outlet pipes should be provided. The system should be designed on a rational basis using seepage principles to estimate the inflow quantities and the outflow conductivity of the drainage system. It should be ensured that the outflow capabilities of the system are at least equal to the total inflow so that no free water accumulates in the pavement structural section. **Fig. 5.10** indicates the arrangement.

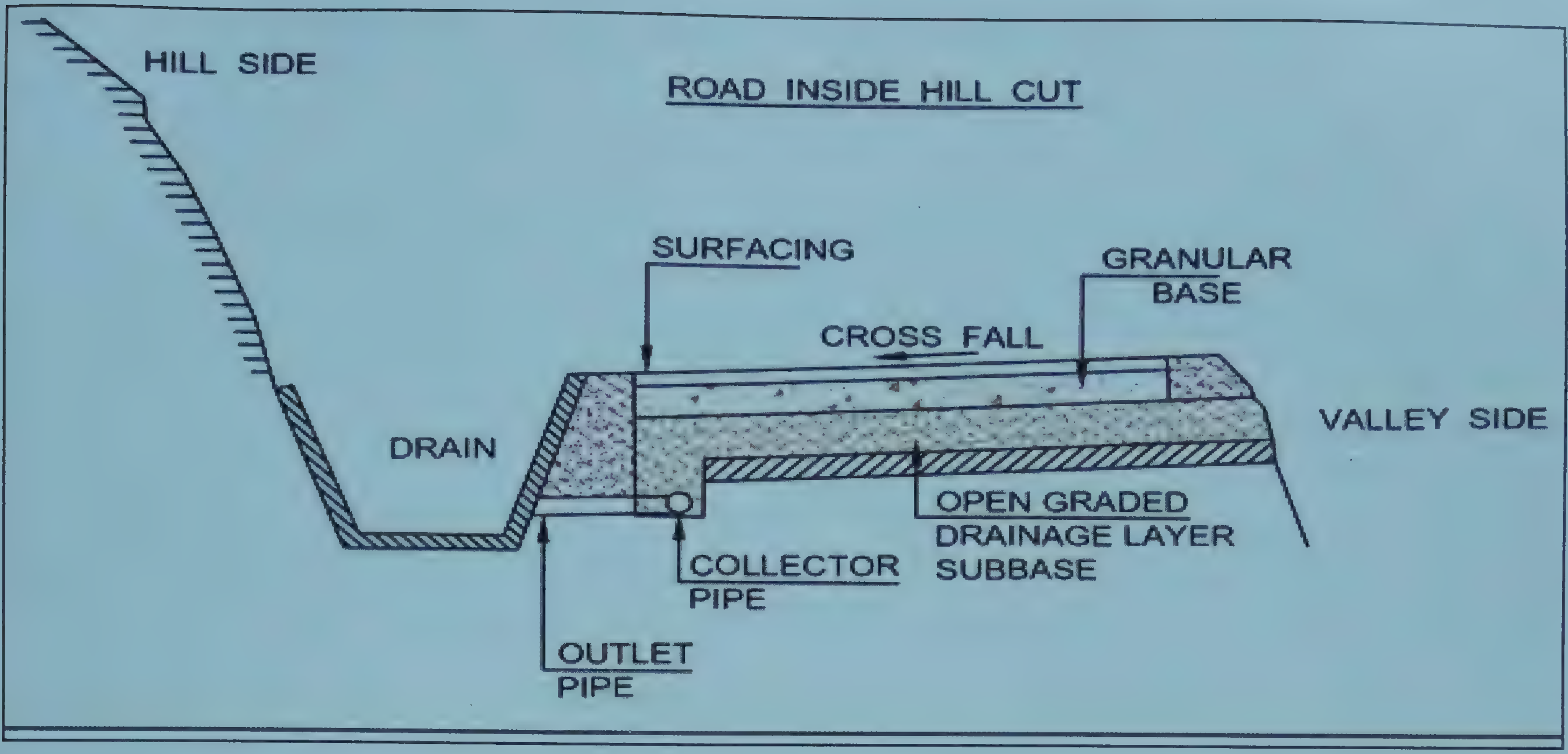

HILL SIDE
ROAD INSIDE HILL CUT
SURFACING
GRANULAR BASE
CROSS FALL
VALLEY SIDE
DRAIN
OPEN GRADED DRAINAGE LAYER
SUBBASE
COLLECTOR PIPE
OUTLET PIPE

Fig. 5.10 Drainage by Pipes

d) Very often, water enters the base, sub-base or the subgrade at the junction of the verges and the bituminous surfacing. To counteract the harmful effects of this water, the shoulders should be well-shaped and, if possible, constructed of impermeable material.

e) To prevent ingress of water into the pavement through shoulders end to end surfacing of roadway could be resorted to as stated earlier also.

5.13 Strengthening of Flexible Pavements

On all National Highways and other important roads where the traffic has reached 1500 CVD on a sustained basis and where the strengthening of the pavement is involved, the design of strengthening measures may be worked out by Benkelman Beam Deflection Technique. The procedure has been outlined exhaustively in IRC:81 “Guidelines for Strengthening of Flexible Road Pavements using Benkelman Beam Deflection Technique”. The design value obtained may be compared with the design evolved for the same data by Cumulative Standard Axle method of design. The strengthening measures to be adopted may be decided based on above as suitable to the ground condition.

6. SNOW CLEARANCE AND AVALANCHE TREATMENT

6.1 General

6.1.1 A large number of roads have now been constructed in the Himalayas, especially in high altitude area. Many of these roads run over high passes, having altitudes above 3000 m and through snow belts and avalanche prone slopes. Large stretches of these roads normally remain closed for six to seven months in a year due to heavy snow fall during winter months and consequent accumulation/compaction of snow at low temperatures, snow drift and avalanches. Keeping these roads open to traffic for longer periods during the year is of vital importance not only for strategic reasons, but also for the welfare of the people living in these areas. The prevailing environmental condition in these areas necessitate specialized methods of snow clearance of roads and avalanche control to minimize the road closure period.

6.1.2 Studies pertaining to snow, ice and related manifestations are only about few decades old in India and the Snow and Avalanches Study Establishment (SASE) is engaged in research and development in the field. Keeping a road open in snow bound high altitude in winter as against closing for winter months would depend on road user requirements and practicability of keeping the road open in winter coupled with the financial outlay involved. In this Chapter, it is aimed to outline the most practicable procedures and solutions to problems concerning snow clearance on roads in the Himalayan region.

6.2 Terrain, Geology and Climatic Conditions

6.2.1 *Terrain and Geology*

The roads prone to avalanche strikes or movement are located altitudes ranging between 2500 m and above. The soil in the area is mostly of glacial origin and found to be unstable in nature and prone to land slides

6.2.2 *Climatic Conditions*

Rainfall is very heavy and goes up to 500 cm in the Eastern Himalayas, even in high altitude snow fall areas, whereas in Western Sector it ranges from 150-250 cm in lower ranges but scanty in higher altitudes. The winter temperature, depending upon the altitude and the place could be as low as -35^{0}C (The temperature goes down to minus 50^0 in certain areas). In summer the day temperature may be as high as 30^{0}C. Velocities of wind exceeding 80 km/h are common, especially near the high passes. The chilling effect of the wind in winter could be devastating and during this period snow clearance operation is near impossible.

6.3 Properties of Snow and Avalanche

6.3.1 *Definition of Snow*

Snow is a mixture of ice, water and air. It may be classified physically as crystalline, granular, powdery pallet snow or mixtures. Crystalline snow has good internal cohesion. Freshly deposited snow is a highly porous permeable aggregate of ice grains. Snow type is drier in western sector than in eastern sector.

6.3.2 *Density of Snow*

The density of fresh snowfall is not affected by wind and is quite low, the values ranging between 0.04 to 0.14 gm per cubic centimeter. Maximum packing and settlement take place within the first 24 hours resulting in the loose snow attaining density of 0.15 gm per cubic centimeter. On further accumulation and time lapse the density of snow may raise upto 0.45 gm per cubic centimeter due to densification of the snow cover. The accumulation may result in standing snow of 8 to 10 mts on the road surface and exceeding 30 meters at avalanche sites.

6.3.3 *Avalanche*

An avalanche is a mass of snow that slides rapidly down an inclined slope, typically on slopes of 30 to 45 degrees, such as a mountainside or the roof of a building. Avalanches are triggered by either natural forces (e.g. precipitation, wind drifting snow, rapid temperature changes) or human activity. In mountainous terrain, they are among the most serious hazards to human life and property. Avalanches are sometimes called also called as snow slides.

An avalanche occurs when stress from the pull of gravity and/or applied load (such as a skier) exceeds the strength of the snow cover. Strength is derived from bonds between snow grains and hence largely depends on morphology of deposited or snowpack.

Avalanche can occur when the following three conditions are present:

I. A snow-covered slope

II. A slab of snow resting on top of a weak layer of snow

III. Triggering mechanism

Triggering mechanisms may be wind, vibrations, or earth tremor, rise in temperature at the end of winter, gravity, heavy snowstorm, and geomorphological features of terrain. Even a falling branch, a hopping animal or a passing plane can trigger an avalanche.

The aforesaid parameter/s must be inspected and reported while fixing or re-planning of hilly roads in avalanche prone areas.

6.3.4 *Terrain and Avalanches Formation*

Terrain plays a very important role in avalanche formation. Steepness, exposition or orientation and shape and type of the surface of the slope contribute a great deal towards avalanche formation. The relation between slope and avalanche formation is given in **Fig 6.1.**

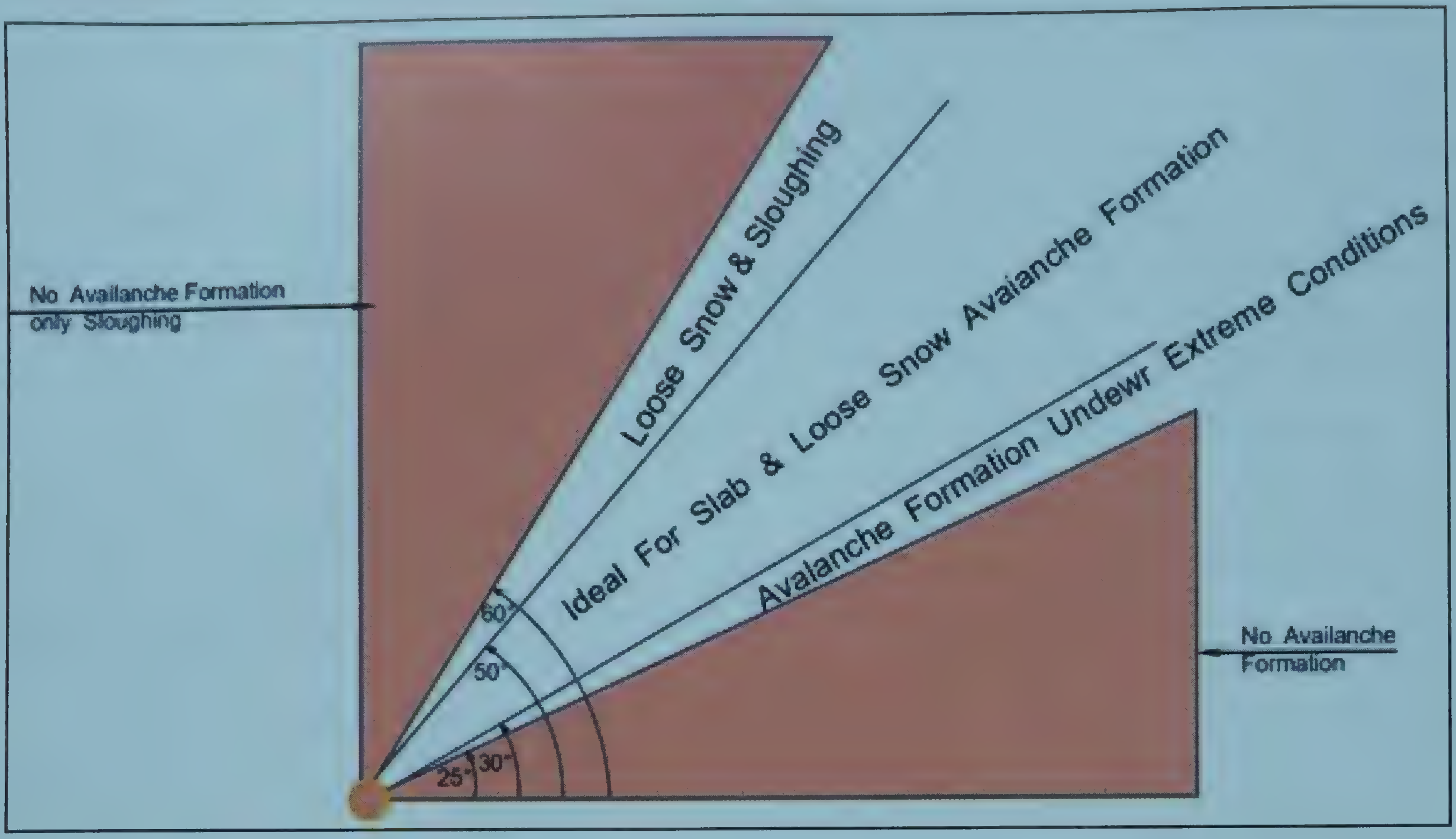

No Availanche Formation
only Sloughing
Loose Snow & Sloughing
Ideal For Slab & Loose Snow Avaianche Formation
Avalanche Formation Undewr Extreme Conditions
No Availanche
Formation
60°
50°
30°
25°

Fig. 6.1 Slope of Terrain & Avalanche Formation

6.3.5 *Type of Avalanches*

Snow avalanches are broadly classified into following categories.

i. Loose snow

ii. Packed snow or slab avalanches

iii. Gliding Avalanche

iv. Powder Avalanche

Loose snow avalanche originates at a point and fan out expanding both in width and depth **(Fig. 6.2)**. Such an avalanche occurs usually during or immediately after a storm and does not pose serious problems unless it is damp or wet.

Slab avalanches have a distinct, broad fracture line. They can occur only when a bonded layer of snow (the slab) is lying on top of a weak layer over a sufficiently large area. Triggering requires the application of an additional load and a slope angle of at least 30°.

Like slab avalanche, gliding avalanches have a distinct, broad fracture line, but they differ in as much as the entire snowpack is released. They can occur only on a smooth substratum, typically consisting of flattened grass or slabs of rock. The steeper the slope, the more likely the snow is to slide.

Powder avalanches arise mostly from slab avalanches. A powder cloud forms in the presence of a large altitude difference when a sufficient quantity of snow becomes suspended in the air. Powder avalanches can reach a speed of 300 km/h and cause tremendous damage. They occur most commonly when the avalanche danger is high or very high.

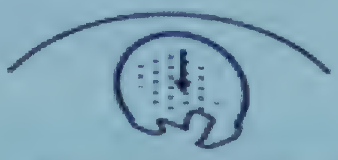
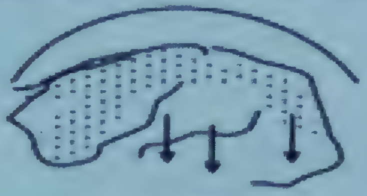
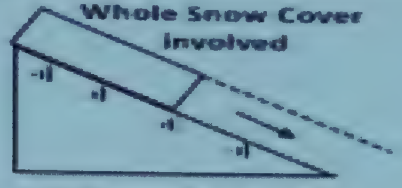
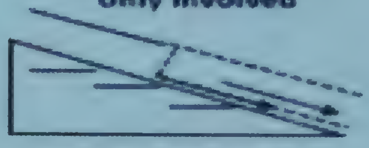
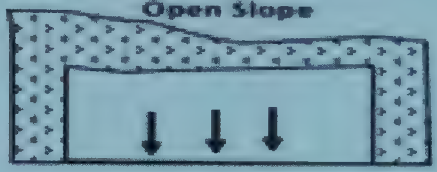
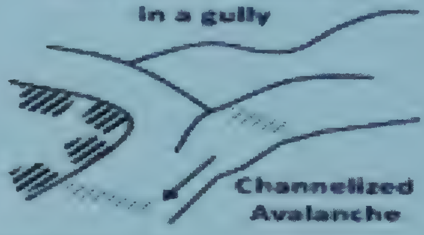
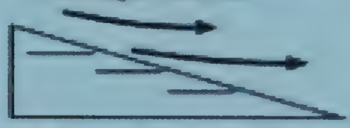
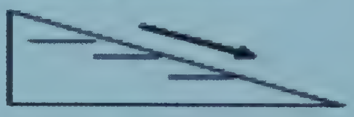
Criteria	Alternative Characteristics and Nomenclature	
1. Type of Break Away	From Single Point  Loose Snow Avalanche	From Large Area Leaving Wall  Slab Avalanche
2. Position of Sliding Surface	Whole Snow Cover involved  Full Depth Avalanche	Some Top Strata only involved  Surface Avalanche
3. Humidity of Snow 4. Form of Track in Cross-section	Dry Snow Avalanche Open Slope  Unconfined Avalanche	Wet Snow Avalanche in a gully  Channelized Avalanche
5. Form of Movement	Through the Air  Air Borne Powder Avalanche	Along the Ground  Flowing Avalanche

Fig. 6.2 Slope and Avalanche Formation

During spring, ambient temperatures go up and the intense solar radiation converts a large portion of snowpack into wet cohesion less mass resulting in wet snow avalanches. Avalanches affect all the major roads in the high altitudes. The avalanches activity is most pronounced in the months of January, February and March and continues even upto April in very high altitude of more than 5000 m.

6.3.6 *Zones of Avalanches*

An avalanche has the following three well defined zones as shown in **Fig. 6.3** and **Fig. 6.4**, and below: -

I. Formation zone or starting zone

II. Middle zone or avalanche path or gliding zone

III. Run-out zone

The starting zone or formation zone is the area where an avalanche is released. The actual precipitation occurs at this zone. The main characteristic of a starting zone is the slope gradient, which influences the release of an avalanche considerably. The slope of an avalanche formation zone is generally more than 30^0. Separate slope $>60^0$ do not help in accumulation of snow and hence changes of avalanche occurrence becomes minimum. Only frequent sloughing keeps on taking place which are of minor nature.

The middle zone or avalanche path or gliding zone of an avalanche track below the formation zone and above the run-out zone, or flow path or slope though which the avalanche glides is known as Middle zone or avalanche path. The slope of this path is generally more than 12°.

The run-out zone is the lowest part of an avalanche area, where the snow mass of a moving avalanche come to a halt because of the decrease of slope or a natural obstacle, is known as the run-out zone. The zone is marked by the debris carried by avalanche waves. The slope of a run out zone is generally less than 12^0.

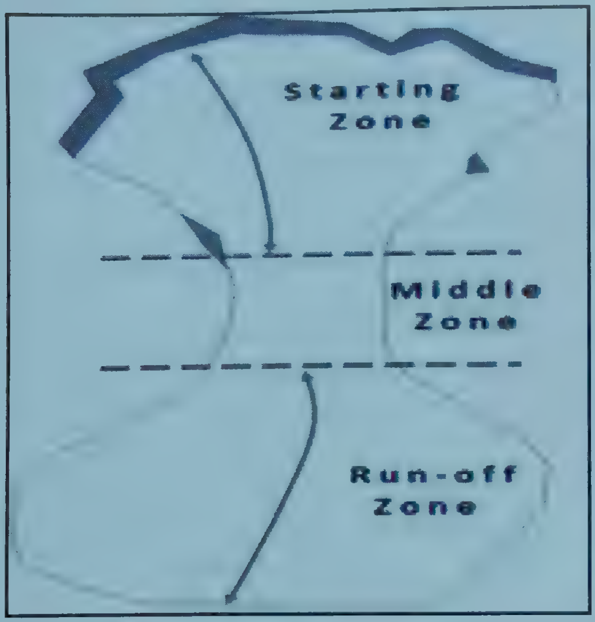


Fig. 6.3 Representation of Avananche Zone

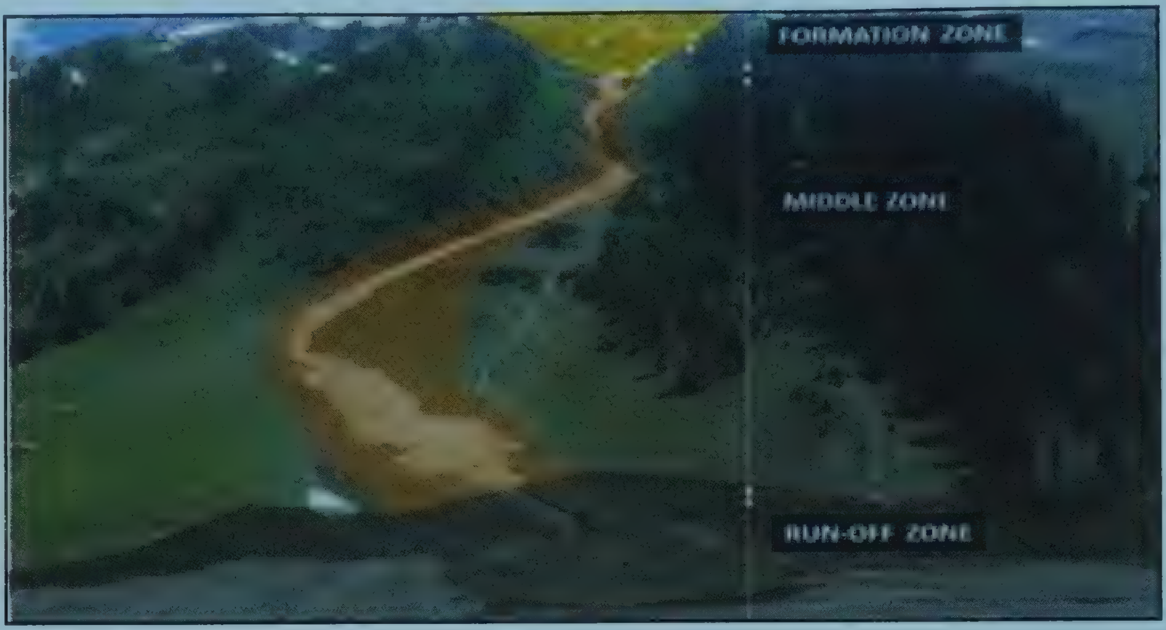


Fig. 6.4 Site Photograph

Note: *It is mandatory to demarcate the zone of the avalanche from which the highway or the road alignment is passing through during fixing or improvement of the alignment.*

6.3.7 *Basic Reporting of Avalanche*

The basic issues to be examined and reported for avalanche control measures along a highway are:

(i) History and local knowledge

(ii) Type of avalanche (eg. powder, slab etc.)

(iii) Zone of avalanche (eg. Formation, middle, run out)

(iv) Magnitude & frequency

(v) Density and extent of deposition

(vi) Climax time of occurrence eg. season, month & time

(vii) Path and velocity of avalanche

(viii) Signs of damage (debris, damage to inhabitants, bridges etc.)

6.4 Estimation of Snow and Snow Properties

6.4.1 *Estimation of Velocity, Density and Froude number*

Each avalanche in the starting zone is a laminar avalanche which starts with a velocity of 10 m/s. This shall be taking the minimum velocity of avalanche. The velocity of the avalanche varies from head to tail.

Therefore, the head has the maximum velocity, the body has a shear velocity and its velocity increases, and its height increases from the ground. The least velocity is observed at the tail as the mass of snow becomes limited and is directed by the existing flow.

The velocity of avalanche depends on the type of snow formation. In absence of field data, the velocities are as tabulated in **Table 6.1.**

Table 6.1 Avalanche Type and Corresponding Velocity

Avalanche Type	Velocity [m/s]
Wet Flow Avalanche	10-20
Dry Flow Avalanche	20-40
Powder Flow Avalanche	30-70

The density of snow formation shall be taken as 300 kg/m^3 for all calculations.

Froude number describes the kinematic similarity between the real and the model avalanches:

$$F_r = v / (g.h)^{1/2}$$

where

Fr Froude number

v Flow velocity, in m/s

g Gravitational acceleration constant, 9.81 m/s^2

h Flow height of the avalanche, in m

6.4.2 *Estimation of Avalanche Pressure*

The avalanche pressure is a function of its velocity of avalanche and density of snow. The avalanche pressure is a product of velocity of avalanche and density of snow. Since, it is very difficult to estimate the exact velocity of avalanche, the estimation of avalanche shall be based on damages and destruction, post occurrence of the event. The avalanche pressure shall be based on observation, in conjunction with the **Table 6.2**, as described below.

Table 6.2 Avalanche Pressure and its Damage Potential

Avalanche Pressure [kPa]	Damage Potential
1	Windows and door smashed
5	Doors are damaged, pushed in or broken
30	Wooden or brick buildings structures damaged
100	Uprooted tree logs, tower, forest debris spread over a large area
1000	Reinforced concrete structure damaged require complete rebuilding

Conversely, the velocity can also be estimated if the damage potential assessed to the true measure. For calculation purpose the higher value of velocity shall be considered as per **Table 6.1.**

In the absence of above data or valid observations, **Table 6.3** shall be followed for estimation of snow/avalanche pressure. The estimation of such pressure shall be supported by data's and observation from Snow and Avalanche Study Establishment (SASE) Defence Geo informatics Research Establishment (DGRE) or Local Meteorological Department.

Table 6.3 Estimation of Avalanche Pressure

Order of Magnitude / Intensity	**Classification according to reach**	**Classification as per damage potential**	**Classification**		
			Runout Length (m)	**Volume (m^3)**	**(KPa)**
Very Low / Snow Sliding	Irrelevant snow distribution in line of slope	Low risk to people	< 50	<100	2
Low / Small Avalanche	Comes from steep slopes area (> 30^0)	Risk to people Burials & Fatalities	< 100	<1000	<10
Average/ mid-sized avalanche	Reaches the foot of slope	Damage cars, houses	<1000	<10000	50
High / Large Avalanche	Covers flatter terrain section < 30^0	Larger destructions damaged cars, risk to people within building, uprooting trees	>1000	<80000	200
Very High / Extreme Events	As yet unknown avalanche track and reach	Total destruction	>1000	Upto 400,000	500

[Reference : Classification of avalanche intensity (destruction potential) according to the reach, the ,potential for damage, as well as according to the criteria of avalanche intensity (runout length, avalanche cubic meters, and pressure effect) (compiled to Canadian Avalanche Association (CAA) [41], Glade and Stötter [77], Rapin [215], Schaerer and McClung [254]

6.4.3 *Estimation/Calculation of Snow Height*

The snow height 'H' is measured in the vertical direction. **(Table 6.4)** It is characteristic of the snow cover in the terrain. When the snowfall is uniform and vertical (no wind), the snow height is independent of the inclination.

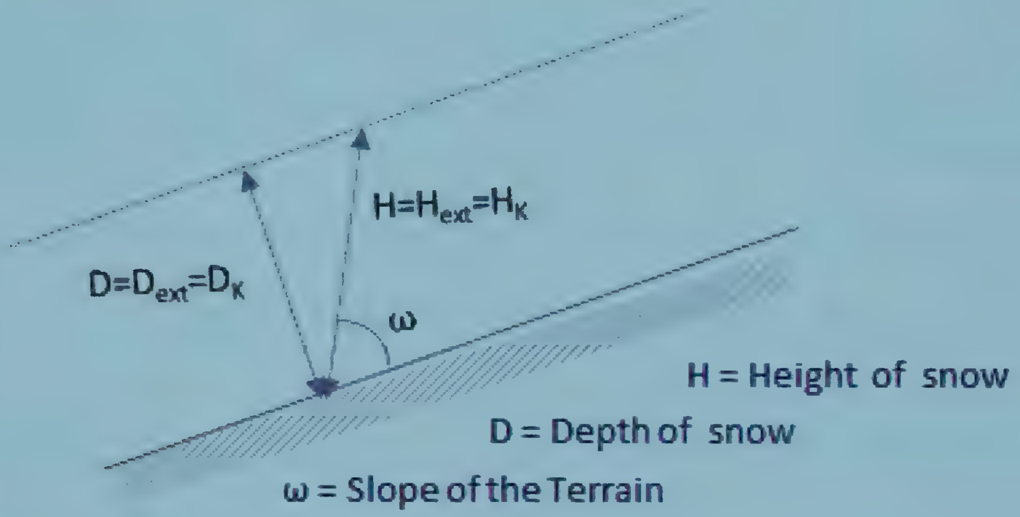
Reports from SASE/DGRE/ Local Meteorological Departments shall be referred to collect the precipitation data or local metrological departments, which ever department gives an extensive timeline on snow precipitation data.

Table 6.4 Snow Height

Abbreviation	Definition
H_{max}	Maximum snow height at a particular point. In this case, where the support system may be installed
$H_{max\ (avg)}$	Average depth of a snow at a particular, averaged over a larger area
H_{ext}	Extreme anticipated maximum value of maximum snow heights over a long period at a particular point
$H_{ext(avg)}$	Extreme occurrence of maximum snow over a larger area that occurs not more than once in 100 years.

Depth of Snow shall be calculated as :

$D = H * \cos \omega$ ..... *where 'ω' is the slope of terrain*


H=H_{ext}=H_K
D=D_{ext}=D_K
ω
H = Height of snow
D = Depth of snow
ω = Slope of the Terrain

[Note : D_{max} , $D_{max\ (avg\ ),}$ D_{ext}, $D_{ect(avg)}$ for which relevant values of H shall be used, as explained in Table. For the purpose of calculation, the maximum value of H shall be used after comparing the Heights in maximum and extreme cases]

6.4.4 *Characteristic of Snow Pressure*

The snow pressure on a supporting structure depends on the following site factors:

ρ min. average density of snow shall be taken as 300 kg/m^3 (if data are not available)

H vertical snow height at site of structure in 'm'

K creep factor*, dependent on density and inclination of the slope

N glide factor, dependent on vegetation, roughness and solar exposure of the ground

f_c altitude factor, characterizing the dependency of the density on altitude

f_R end-effect factor, dependent on the lateral distance between structures (and on the arrangement of the structures) and on the glide factor.

6.4.4.1 'f_c' Altitude factor correction

The glide factor 'N', which expresses the increase in snow pressure for movement of the snow cover along the ground. The values of altitude correction factor may be referred to the following table.

Altitude Factor as a Function of Altitude

Z:	m a.s.l.	1500	1600	1800	2000	2200	2400	2600	2800	300
f_c:	-	1.00	1.02	1.06	1.10	1.14	1.18	1.22	1.26	1.30

6.4.4.2 *'K' Creep Factor*

The values for the creep factor K as a function of the density and the inclination of the slope. The dependency on inclination in the region 35°–45° shall be neglected.

Creep factor K as function of average snow density (ρ) and slope inclination (Ψ).

$\rho[t/m^3]$	0.2	0.30	0.40	0.50	0.60
$K/\sin 2\Psi$	0.7	0.76	0.83	0.92	1.05

6.4.4.3 *'N' Glide Factor*

The glide factor N, which expresses the increase in snow pressure for movement of the snow cover along the ground, depends on the ground roughness and the slope exposure or solar exposure or geothermal energy.

The values assumed for different terrain & situations are mentioned in **Table 6.5.**

Table 6.5 Estimation of Glide Factor

Type of Terrain	Glide Factor 'N'
Rough, undulated terrain with boulder debris, or terrain covered with large boulders > 150 mm without vegetation except grass cover	1.3
Area covered with forest, bushes, shrubs > 1.00 m height height dense vegetation	1.8
Terrain covered with short shrubs < 1.0 m height, or fine pebbles,or small boulders < 150 mm in size or small turfs	2.4
Smooth slope, with grass cover, fairly smooth terrain,exposed rock plane parallel to slope - facilitating snow movements	3.2

Reference: Swiss Guidelines for avalanche defence structures

6.4.4.4. *Height of structure (H_k)*

The height of the structure H_S is defined as the average vertical distance from the upper edge of the supporting surface to the ground.

The height of the structure shall always be greater than the extreme height of the snow (1.5* H_{ext}), it can be written as

$$H_K > H_{ext} \text{ and } H_{k} = 1.5\, H_{ext}{}^{*}$$

*[*Extreme High data can be collected from SASE*

or State Metrological Department]

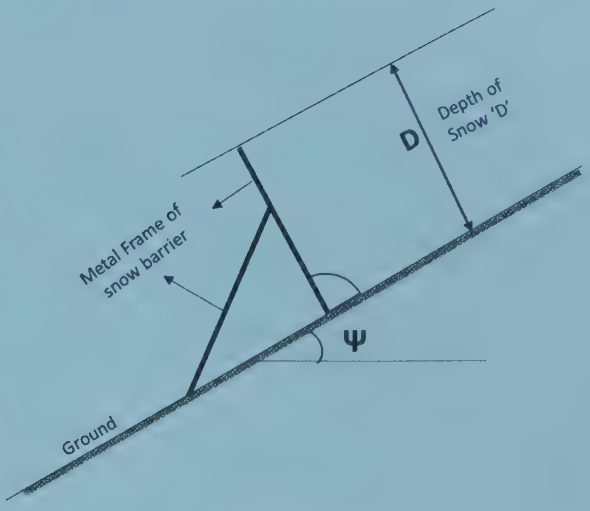
6.4.5 *Calculation of Snow Pressure*

Snow pressure 'S_n' is assumed to be evenly distributed of the surface of snow rakes or snow nets during its exposure to snow. This may be calculated as below

(i) Snow Pressure Parallel to the Slope (in KN/m²)

The component of creep and glide pressure in the line of slope on a rigid supporting surface lying normal to the slope and of infinite length in the contour line amounts to

$$S_n = \rho * g * \frac{H^2}{2} * K * N$$


Depth of Snow 'D'
D
Metal Frame of snow barrier
Ψ
Ground

(ii) Snow Pressure Perpendicular to the Slope (Sq in KN/m²)

The snow pressure component normal to the slope S_q on a snow supporting structure appears when the settlement movement of the snowpack is prevented because of the roughness of the support surface.

It assumed and calculated on a rigid, endlessly long support surface, vertical to the slope and at level line, as follows, where S_q simplified can be assumed to be distributed evenly across the height:

$$Sq = Sn * \frac{a}{N * \tan\psi}$$

a = varies between 0.2 and 0.5 (from Loose snow to dense snow)

Ψ = Slope gradient [°]

ρ = Average density of snow (in t/m3)

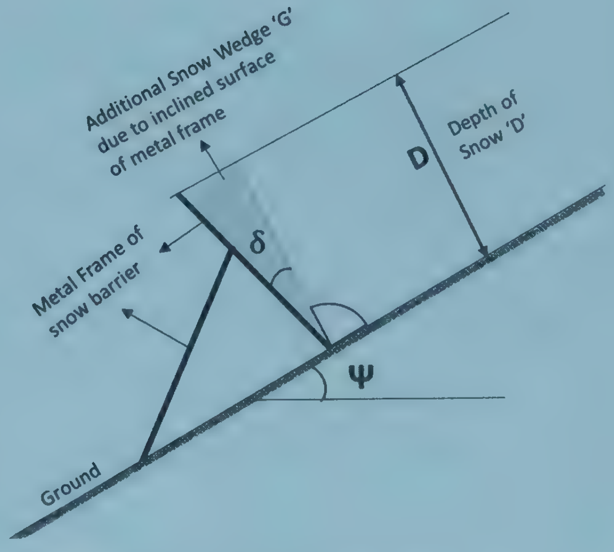
H = Vertical snow height at site of structure

K = Creep factor

N = Glide factor

S_n = Snow pressure normal to slope

When the snow holding surface of the snow barrier(structure) is not normal to the ground, an additional snow loads, the wedge 'G', shall also be taken in consideration for snow loads, which is an additional space created due to inclination of the structure from the normal. It shall taken as


Additional Snow Wedge 'G' due to inclined surface of metal frame
D
Depth of Snow 'D'
δ
Metal Frame of snow barrier
Ψ
Ground

Based on SLV Guidelines Switzerland

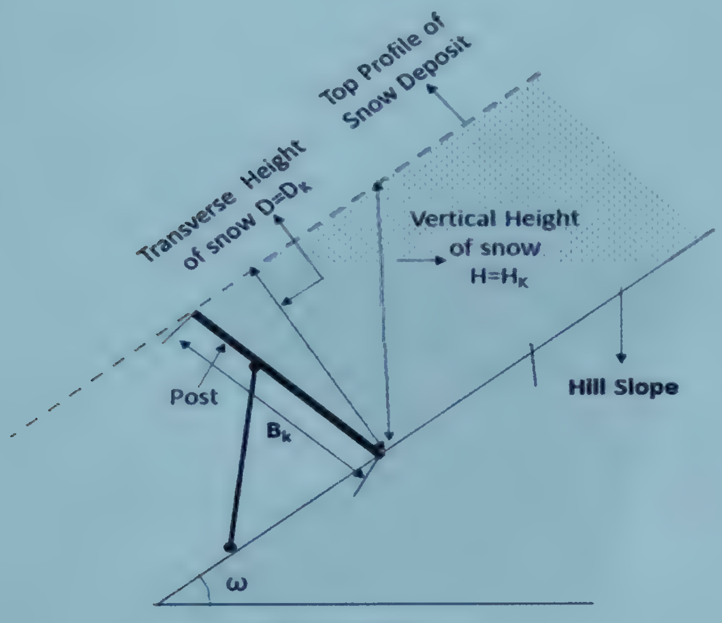
$$G = 1.5 * \rho * D_k^2 * tan\delta \; (in \; kN/m)$$

where:

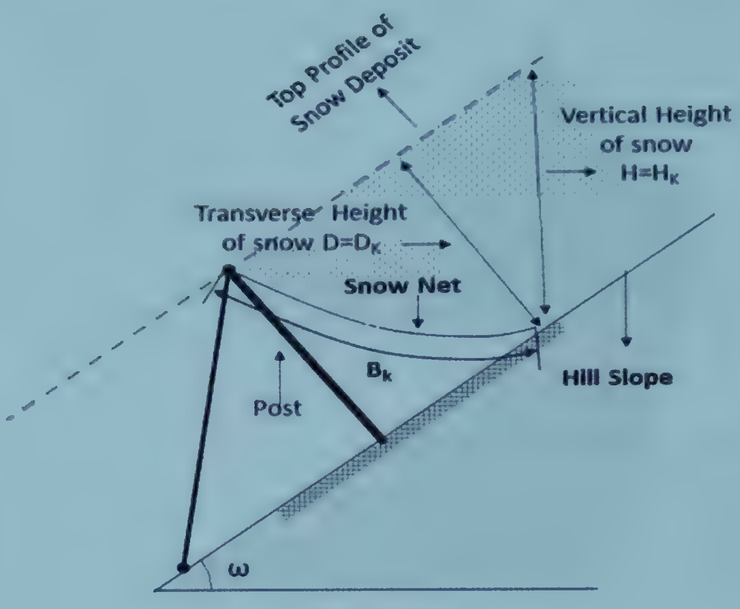
DK = Effective grate height [m], where
*DK = HK*cosψ*

δ = Angle between support surface and the normal to the slope in [°]

6.4.6 *Determination of Height of Snow Rakes or Snow:* The grate or net height B_K is defined as the average width of the supporting surface normal to the contour line. It is bounded at the lower end by the surface of the ground.


Top Profile of Snow Deposit
Transverse Height of snow D=D_K
Vertical Height of snow H=H_K
Post
B_K
Hill Slope
ω

Grate Height


Top Profile of Snow Deposit
Vertical Height of snow H=H_K
Transverse Height of snow D=D_K
Snow Net
B_K
Post
Hill Slope
ω

Net Height

Note:

Grate height pertains to height of Snow Rakes and Net Height pertains to height of Snow Nets

The effective grate or net height D_K is defined in a similar way to the snow thickness as the average distance of the upper edge of the supporting surface from the ground normal to the line of slope.

6.4.7 *Perpendicular Distance between Structures in formation Zone*

The structure must be so spaced, that it does not suffer any damage from snow loads. Dynamic loads resulting from snow movement must be resisted by the structures with causing any damage to the structures. The distance between the structures shall be restricted so that the snow movement is contained within the limiting values like velocity or mass accumulated.

The slope-parallel distance between structures '*L*' shall be calculated as below:

$$L = f_L * \mathbf{H_K}$$

where:

f_L = Distance factor

H_K = Structure height in [m]

The distance factor f_L depends on following factors:

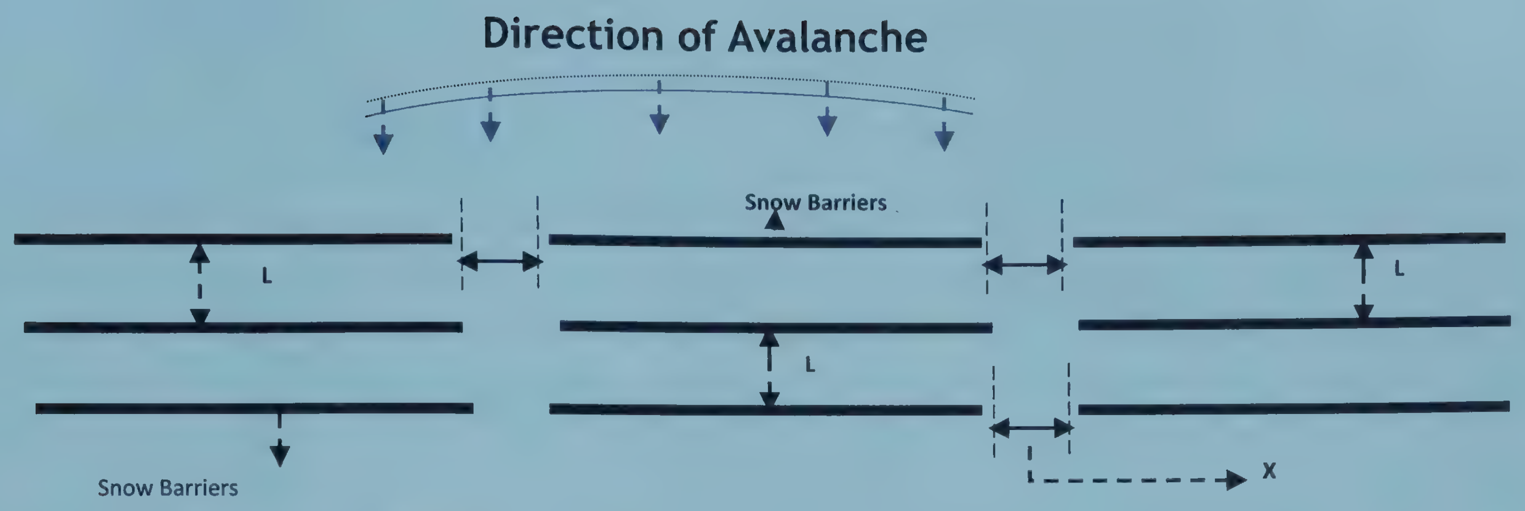
(i.) the slope gradient,

(ii.) height of the Structure

(iii.) the creep factor of snow

(iv.) the angle of friction tan ϕ between the soil and the snow.

Where the inclination varies within the structures, ψ is chosen as the inclination of the straight line between the foundations of the relevant structures in calculating L. It can be calculated using the **Fig. 6.5**.


Direction of Avalanche
Snow Barriers
L
L
L
X
Snow Barriers

X = Transverse Distance < 1.5 m
L = Perpendicular Distance (*as per table no 6.6*)

Fig 6.5 Perpendicular & Transverse Spacing of Avalanche

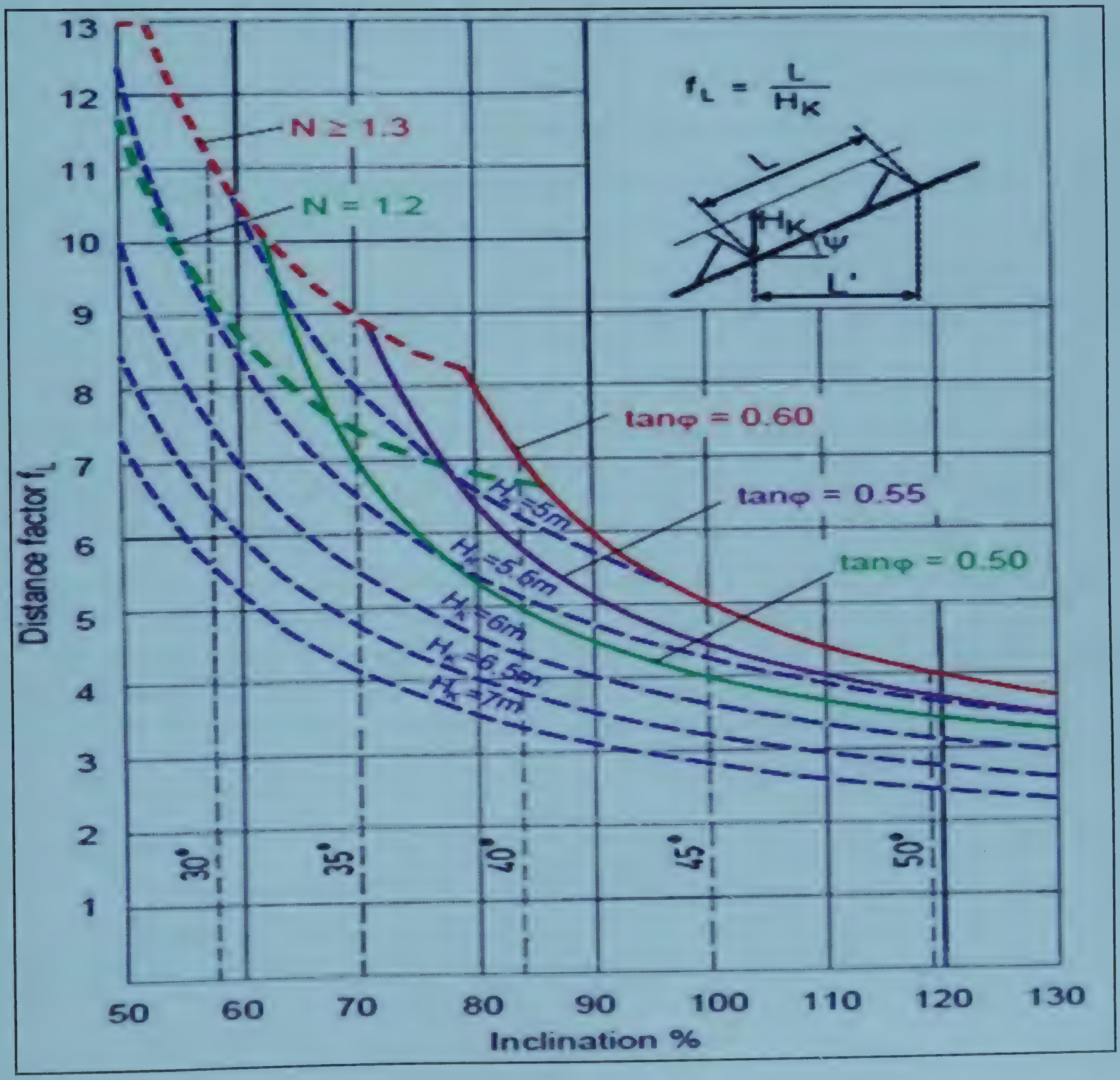


Table 6.6 Slope-Parallel Distances between Rows of Structures according to the Swiss Guidelines

6.5 Avalanche Control

6.5.1 *General*

To tackle the problem of avalanche control appropriately, a fairly accurate knowledge and data is necessary of the type of avalanche frequency at the location, its magnitude and intensity, extent of spread and the return period of the climax avalanche, which is the avalanche that causes maximum damage and havoc. In absence of adequate information and data available on past avalanche activity, recourse may be taken to indirect evidence as under.

a. Air photo interpretation of avalanche slopes

b. Study of forest on avalanche prone slopes

c. Obtaining information of avalanche occurrence/accidents.

It is recommended to contact the Local Center for Snow and Avalanche Study Establishment (SASE) also known as Defence Geological Research Establishment (DGRE) for required details and data's to substantiate the reports and records.

6.5.2 *Avalanche Control/Defense Structures*

Avalanche control/defense structures refers to any measure adopted in the respective avalanche zones to stop the avalanche triggers from their release zones or zone from which the avalanche may passes during it flow process.

These structures can be classified in two categories

i. Active defence measures

ii. Passive defence measures

Active defence measures prevent avalanches from starting or act directly on the flow process, while passive defense measures mitigate the consequences of a potential avalanche hazard.

Corresponding to their nature and mode of action, three different type of structures can be distinguished. Structures in the formation zone which prevent avalanches, structures in the avalanche path/gliding zone which deflect or reduce the momentum of avalanches and structures in the run-out zone which reduce the damaging effect of the avalanches by containing the avalanche discharge. Formation zone control is most effective and permanent solution to the avalanche control problem.

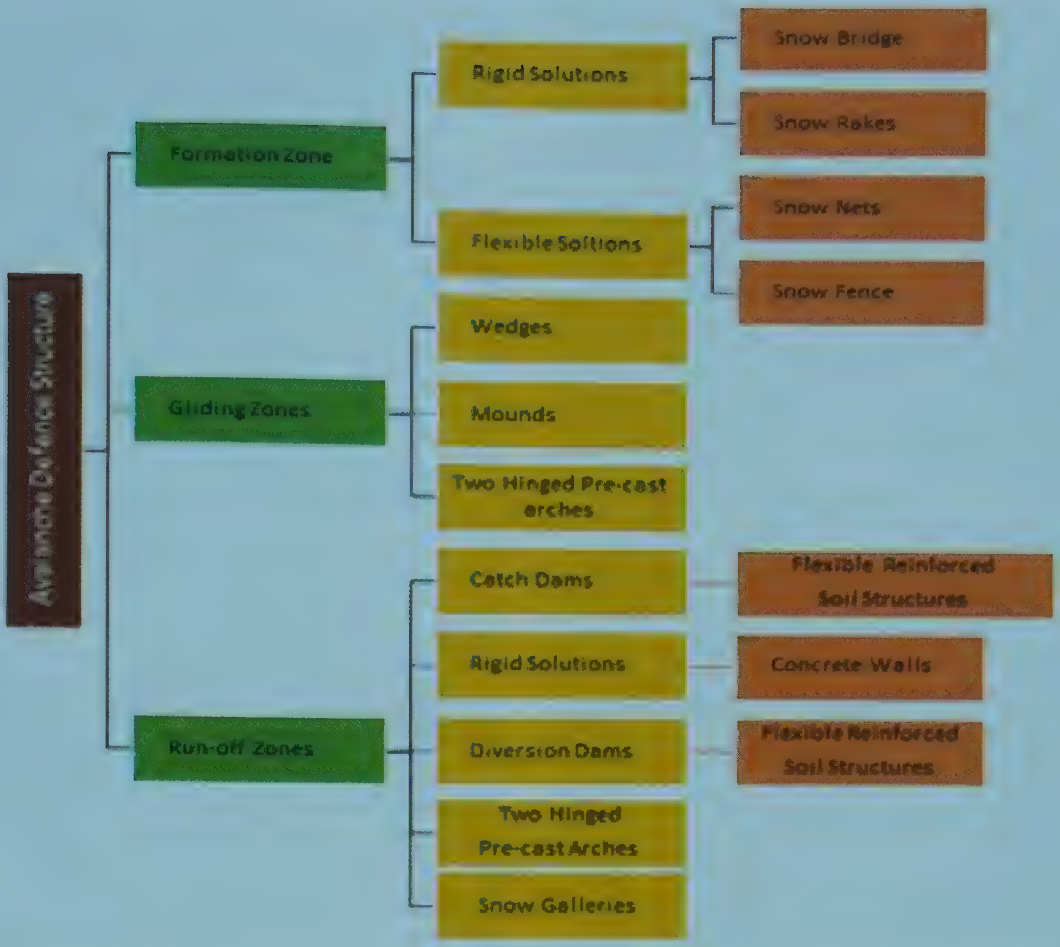

Avalanche Defence Structure
Formation Zone
Rigid Solutions
Snow Bridge
Snow Rakes
Flexible Soltions
Snow Nets
Snow Fence
Gliding Zones
Wedges
Mounds
Two Hinged Pre-cast arches
Run-off Zones
Catch Dams
Flexible Reinforced Soil Structures
Rigid Solutions
Concrete Walls
Diversion Dams
Flexible Reinforced Soil Structures
Two Hinged Pre-cast Arches
Snow Galleries

Fig 6.6 Guideline for Adoption of Avalanche Defense Structure

6.5.3 *Requirement of Avalanche Supporting Structures*

Avalanche control structure must be designed and chooses to suit the local conditions at site or location as per the zones in which they would be required.

The requirements apply to the planning of supporting structures in the avalanche starting zone or near formation zone. It is mandatory to choose the correct dimension and data for precipitation before dimensioning those structures. The following variables and their existence shall be verified before proceeding. The following data should be collected from site.

- Slope inclination or gradient of terrain
- Thickness of snow bed
- Roughness of Ground (terrain details like grass, forest, rock bed, debris etc.)
- Snow characteristics (loose, sluff or slab)

6.5.4 *Structures in the Formation Zone*

Avalanche supporting structures are erected in the starting zones at substantially high altitudes which are not easily accessible most of the times **(Fig. 6.7 & 6.8)**

Therefore, it is necessary to use simple, lightweight, robust, and well-proven structural methods which are essential for successful, durable, implementation of avalanche defense structures.

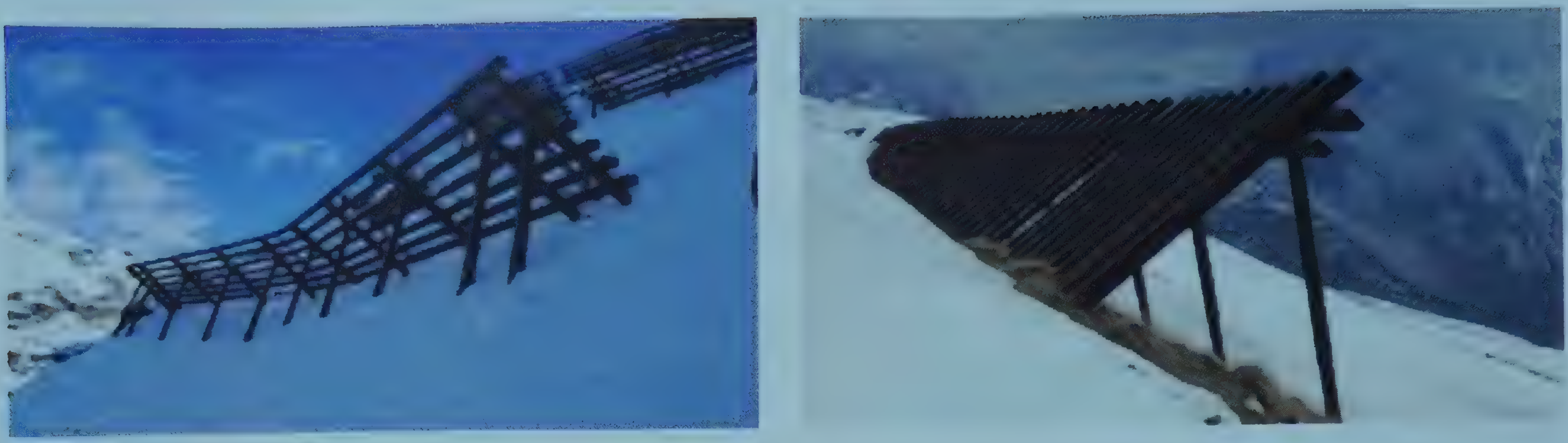
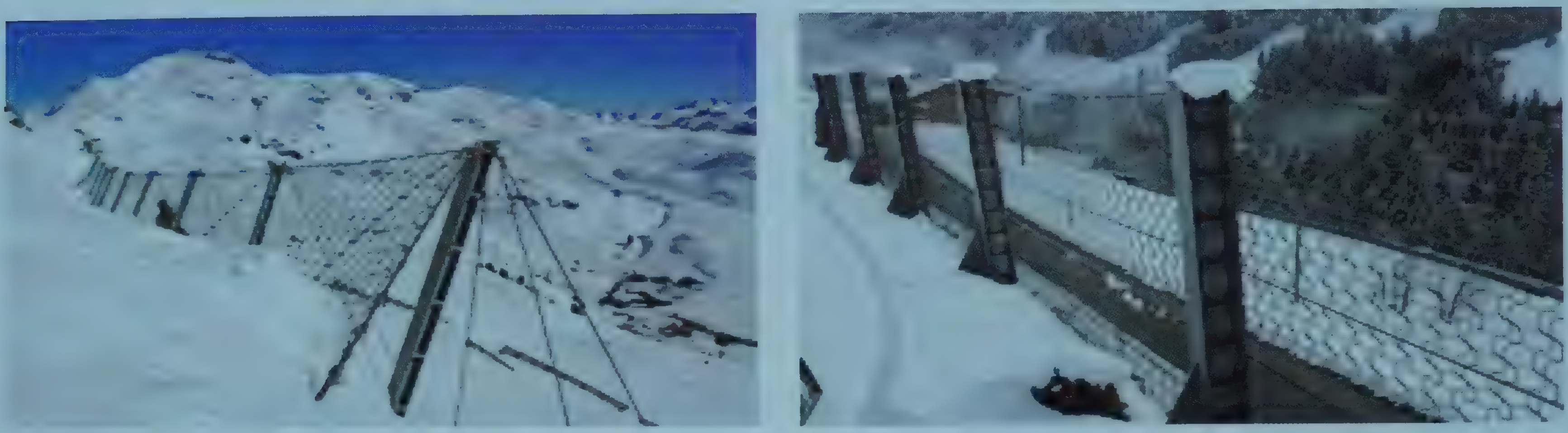
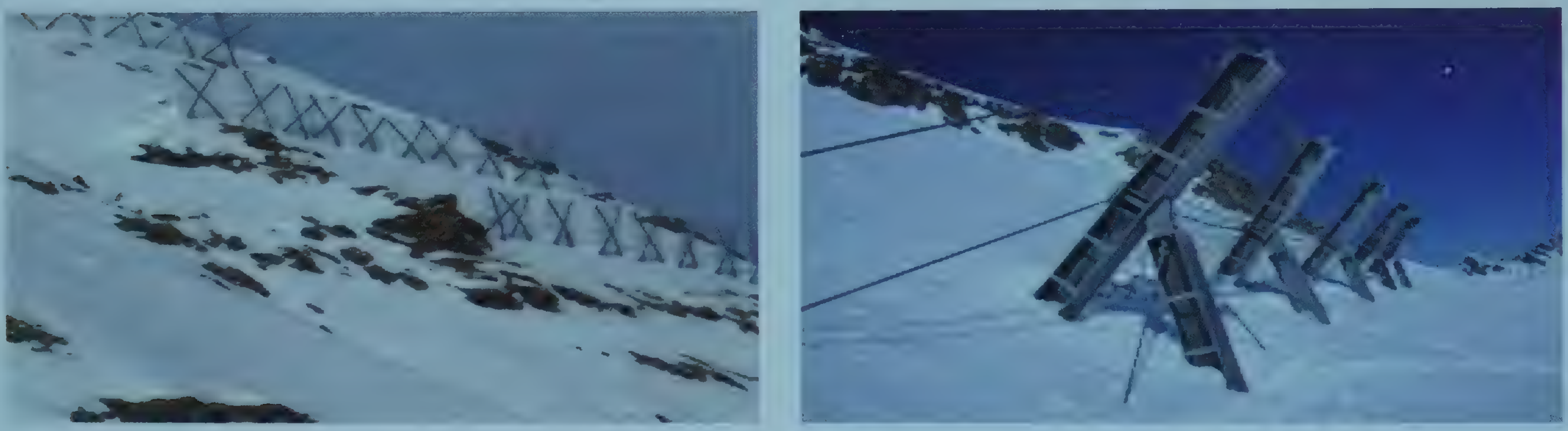


Fig. 6.7 "Rigid Type" Avalanche Defence Structures in "Formation Zones"



i. Snow Net *(Trumer-Austria)*

ii. Snow Fence *(Trumer-Austria)*



iii. Umbrella Type Snow *(Incofil-Italy)*

iv. Snow Rakes with Cable

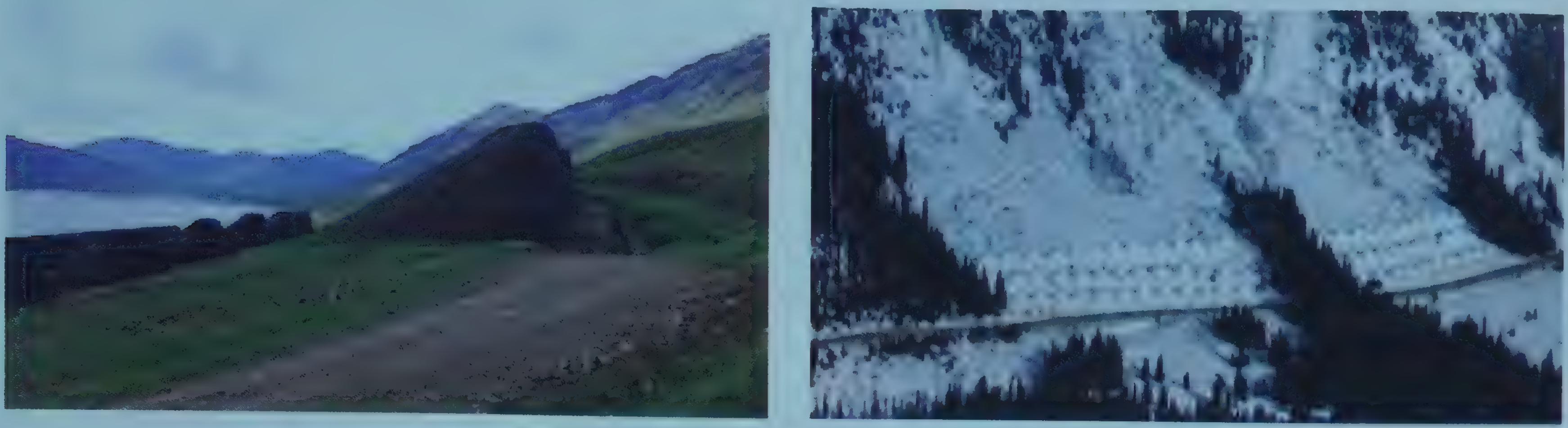
Fig. 6.8 "Flexible Type" Avalanche Defence Structures in "Formation Zones"

6.5.5 *Structures in the Middle Zone*

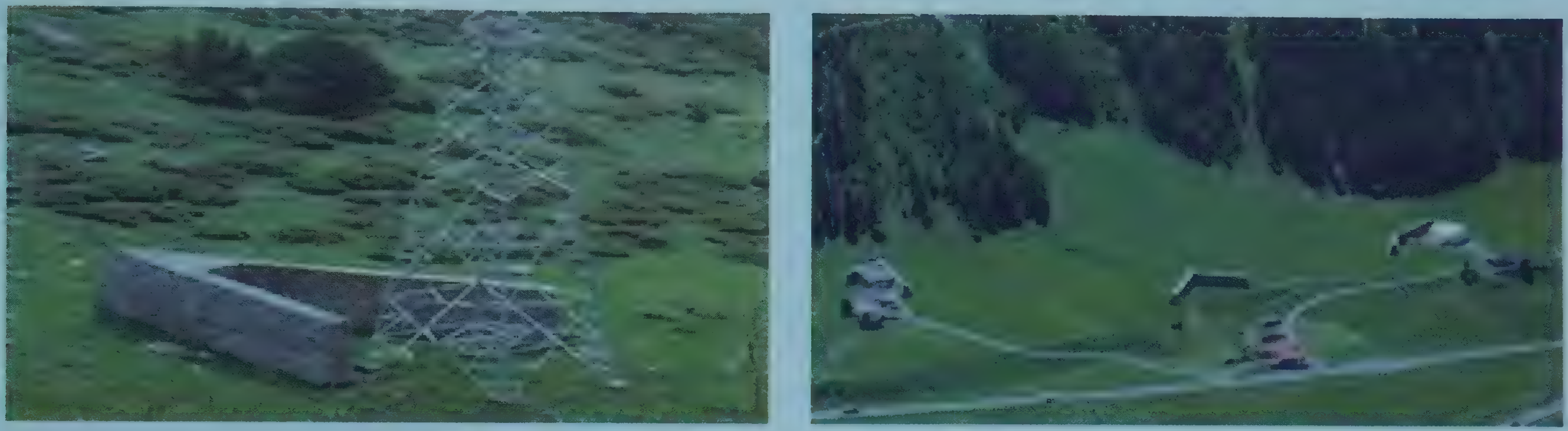
If construction of protection measures in the starting zone is not feasible because of cost economy or unfavorable conditions for foundations or reach, technical defense can be implemented in the middle zone usually in the form of deflecting or retarding structures, wedges, splitters or wall **(Fig. 6.9)** These structures can be a masonry, concrete, or reinforced soil wall structures to reduce to reduce the run out distance of the avalanches. These structures can be very effective in protecting bridge piers, highway establishments etc.

If the road alignment is passing through this zone, it will be an effective solution to use cast-in-situ snow sheds or RCC pre-cast cut and cover tunnels to bypass the avalanche from above those structure.

Braking mounds are used to retard avalanches by breaking up the flow and causing increased dissipation of kinetic energy in the middle zone.



i. Mounds **ii. Group of Mounds**



iii. Avalanche Splitters **iv. Avalanche Deflectors**

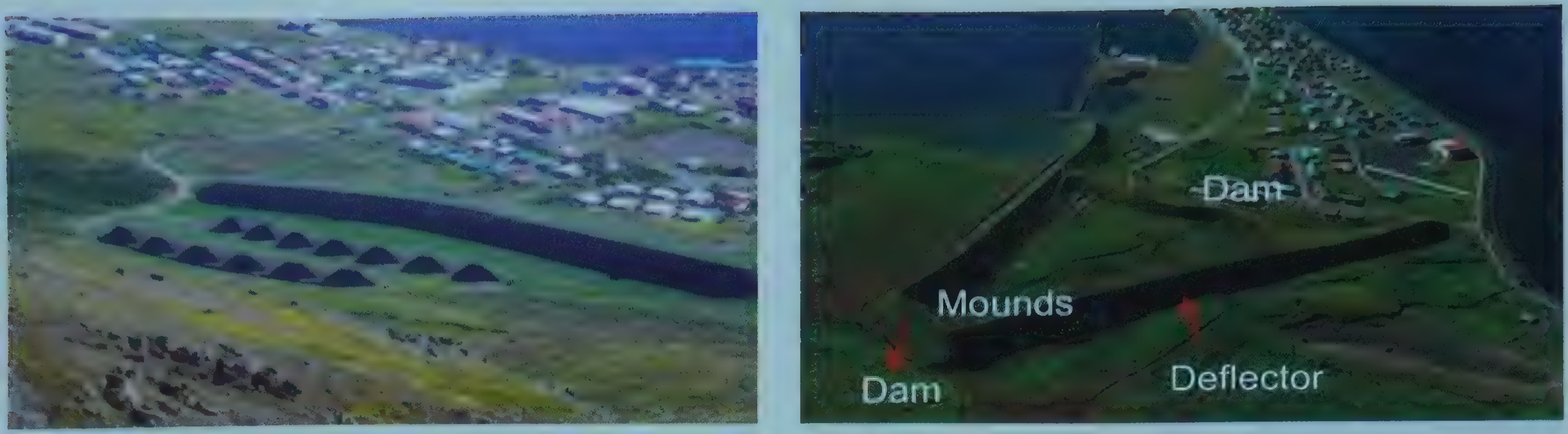
Fig. 6.9 Avalanche Defence Structures in "Gliding Zone" ***(Source France)***

6.5.6 *Structures in the Run-off Zone*

Structures in the runout zone **(Fig. 6.10)** are aimed at containment of the avalanche and avalanche debris to reduce the fanning area and protect structures, inhabitants, or establishments or objects at risk behind the structure. Since, avalanche flow pressure is high in these zones, the intended structure for containment must be flexible in nature so that it can absorb the impact and the zero down the momentum of the avalanche. Avalanche dams (also known as catching dams) or deflecting structures can be adopted in these zones.

The structures are typically used for extended areas along the foot of the slope where there is insufficient space. Concrete structure may be adopted for height below 2.00 m, while for higher heights reinforced soil structures stands shall be chosen as most feasible options.

i. Flexible Avalanche Dam **ii. Snow Breakers**



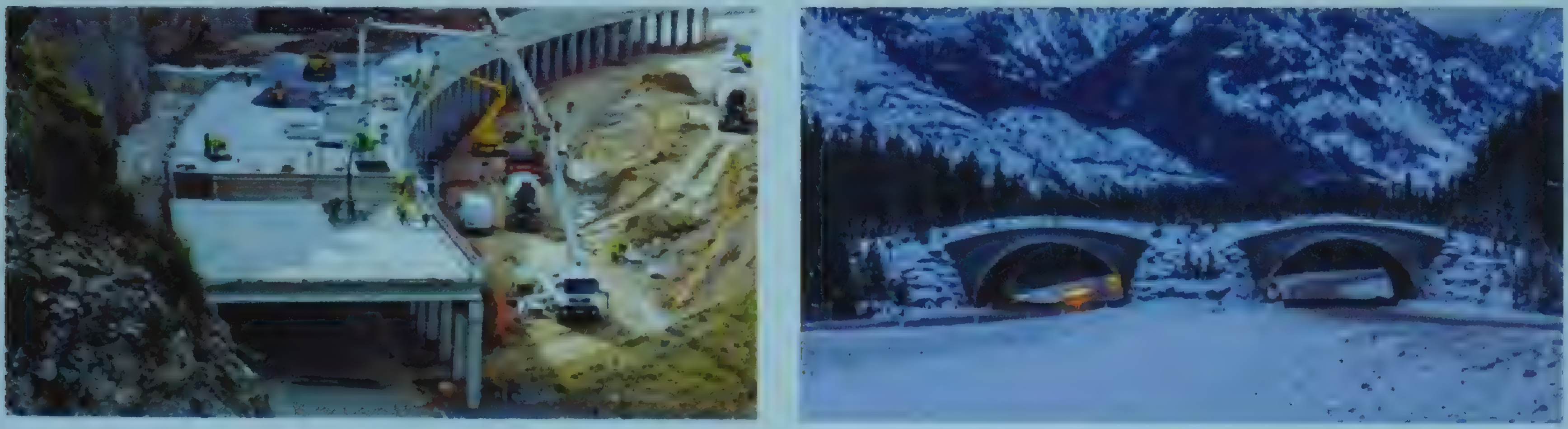
iii. Avalanche Splitters **iv. Avalanche Deflectors**

Fig. 6.10 Avalanche Defence Structures in "Run-Out Zone"

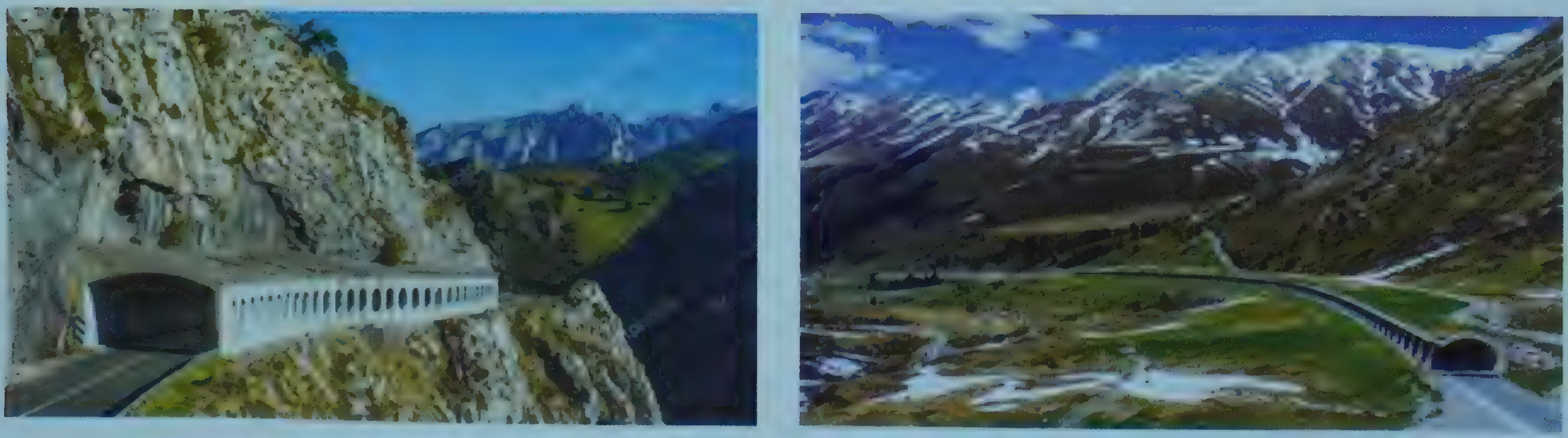
6.5.7 *Other Structures for Avalanche Protection*

Other potential protection system may pertain to crossing structures in which the avalanche may be allowed to pass of the road alignments. Various types of structures can be suggested depending upon the construction period, space constraints, traffic disruptions etc.

Since, in the Himalayas, the construction period is limited to 6.0 to 8.0 months, precast system such as Two Hinged RCC precast arches can be adopted to make the roads pliable in shortest possible time **(Fig. 6.11)**



i. Cast in Situ Avalanche cum Rockfall **ii. RCC Pre-Cast Arch Sheds**



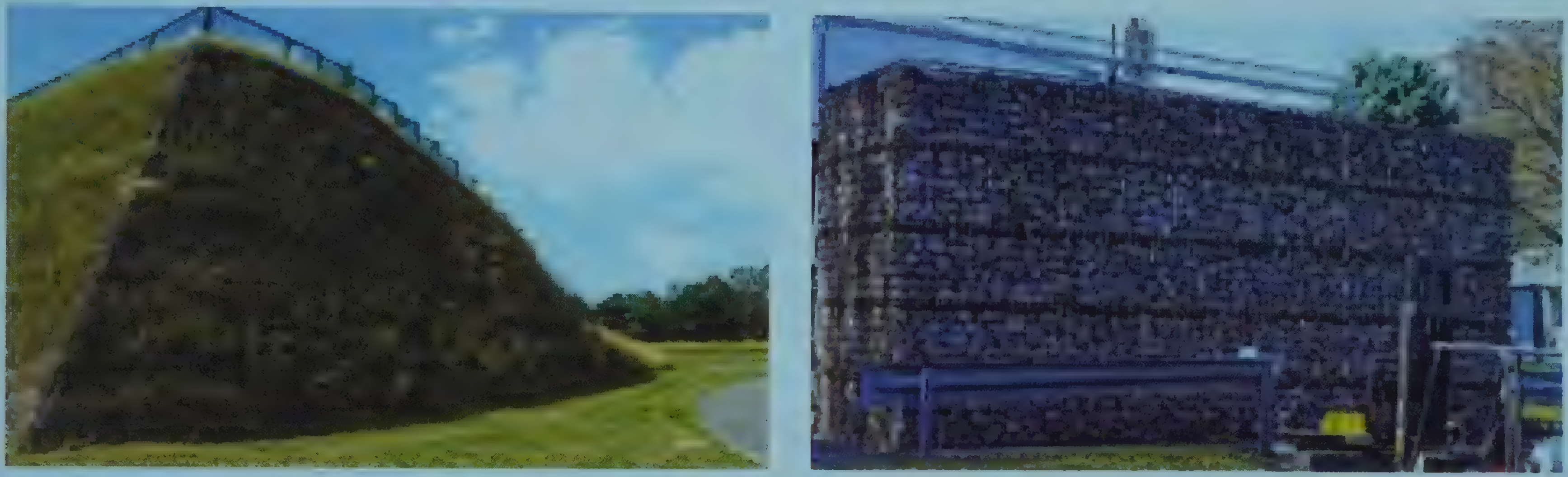
iii. Cast in-situ Snow Sheds **iv. Semi-Circular Pre-cast Arch Sheds**

Fig. 6.11 Other Types of Defence Structures *(Source France)*

6.5.8 *Protection against Powder Avalanche*

Powder avalanche that are generated due to slab avalanche can be very destructive in nature and cause considerable damages to inhabitants or highway establishments or structures in the causing zones.

Depending upon the flow height of power avalanche blast protection wall can be adopted at those locations. These blast **(Fig.6.12)** wall can be made up of concrete or reinforced soil structure with flexible fascia system to absorb the energy of the powder avalanche during the event. These systems have capacity to resist energy level of 5000 KJ and can be made by using locally available materials.



i. Flexible Reinforced Soil Splitter type Blast Walls

ii. Thin Section Blast Walls

Fig. 6.12 Defence Structures for Powder Avalanche

6.6 Snow Clearance Operation Strategies

Various roadway snow and ice control strategies can be used in winter maintenance operations further can be classified into four general categories as below:

- Anti-icing,
- De-icing,
- Mechanical removal of snow and ice together with friction enhancement, and
- Mechanical removal alone

6.6.1 *Anti-icing*

Anti-icing is a general strategy that attempts to prevent the formation of ice/pavement bond by the timely application of ice control chemicals. Chemicals may be applied before the event (pre-treating), early in the event, and as necessary throughout the event.

6.6.2 *De-icing*

De-icing is a strategy of allowing ice/pavement bond to form during an event and periodically treating it with chemicals until the ice/pavement bond is broken and snow/ice can be mechanically removed or displaced by traffic.

6.6.3 *Mechanical Removal of Snow and Ice*

Mechanical removal is the displacement of snow/ice from the roadway by plows, rotary plows (snow blowers), brooms, and other mechanical means. This approach, as a strategy, is capable of producing low within- and after-event LOS (level-of-service). At pavement temperatures above 0°C and below about -10°C, higher level-of-service may be possible with mechanical removal.

6.6.4 *Mechanical and Abrasives*

The practice of ploughing snow and spreading abrasives (either straight or mixed with a small amount of chemical) is common on lower-volume roads. It also may be a necessary treatment due to low pavement temperatures. As a strategy by itself, it only is capable of producing low within- and after-event LOS(level-of-service) unless a very warm pavement temperature above 0°C is involved that does not allow ice/pavement bond to occur.

6.6.5 *Mechanical and Anti-icing*

Timely mechanical removal of snow/ice within an event, in conjunction with an overall anti-icing strategy, will produce the highest possible level of service within and after events.

6.6.6 *Mechanical and De-icing*

Mechanical removal in conjunction with a de-icing strategy within an event will produce medium level of service within and after winter weather events. This primarily results from controlling the depth of loose snow and ice on the roadway.

6.6.7 *Mechanical and Pre-wetted Abrasives*

Mechanical removal plus treatment with abrasives that have been pre-wetted with liquid chemical is capable of producing low within- and after-event LOS. Pavement temperatures above 0°C that will not allow ice/pavement bond may allow higher level of service to be achieved.

6.6.8 *Anti-icing for Frost/Black Ice/Icing Protection*

Use of a liquid ice control chemical for pre-treating areas susceptible to frost/black ice/icing that may occur in the absence of precipitation is a proven effective anti-icing tactic that prevents ice formation. Since the ice does not form, the level of service is always high.

6.6.9 *Surface Treatments*

The surface treatment of pavement surface can be done in following ways: -

6.6.9.1 Salt/brine spray

Salt is spread along the carriageway as a de-icing agent and acts as an alternative for snow removal. The figure below shows the spraying of salt/brine along the roadway. The salt spraying device is generally added on the backside of the plow's.

6.6.9.2 Sand / abrasive spray

The use of abrasives in winter maintenance is a well-established practice. Typically, sand is placed on the road. The sand is intended to increase friction between vehicles and the (often snow or ice covered) pavement. The sand may be applied "straight" or by pre-wetting the abrasives at the spinner, as they are placed on the road or heating the abrasives to high temperatures (about 180° C seems to be effective) just prior to being placed on the road, or by mixing the abrasives with hot water (about 90° C) as they are placed on the road.

6.6.9.3 *Calcium Magnesium Acetate (CMA)*

Calcium magnesium acetate is an alternative to road salt. Calcium magnesium acetate works by interfering with the bond between snow particles and the road surface; in contrast, road salt chemically breaks down snow and ice as it moves downward from the surface. CMA, a solid, has a deicing range closer to that of salt.

6.6.9.4 *Potassium Acetate*

Liquid potassium acetate is an organic, biodegradable fluid that is used for de-icing and anti-icing roads. As opposed to rock salt or other alternative road deicers, such as urea-based or glycol-based products, potassium acetate has less of an environmental impact, while being more efficient at removing ice. On top of being a good deicer, it is more effective as an anti-icer, and can also be used as a "pre-wetter" with other solid deicers to enhance their performance.

6.6.9.5 *Anti-Skid Treatments*

It consists of spreading beforehand de-icing salts on roads and/or anti-icing mixtures (salts and aggregates) in order to prevent ice formation on pavements, on bridges and viaducts, near tunnels (entrance/exit portals). A brief of antiskid treatments is as shown in **Fig. 6.13** below:

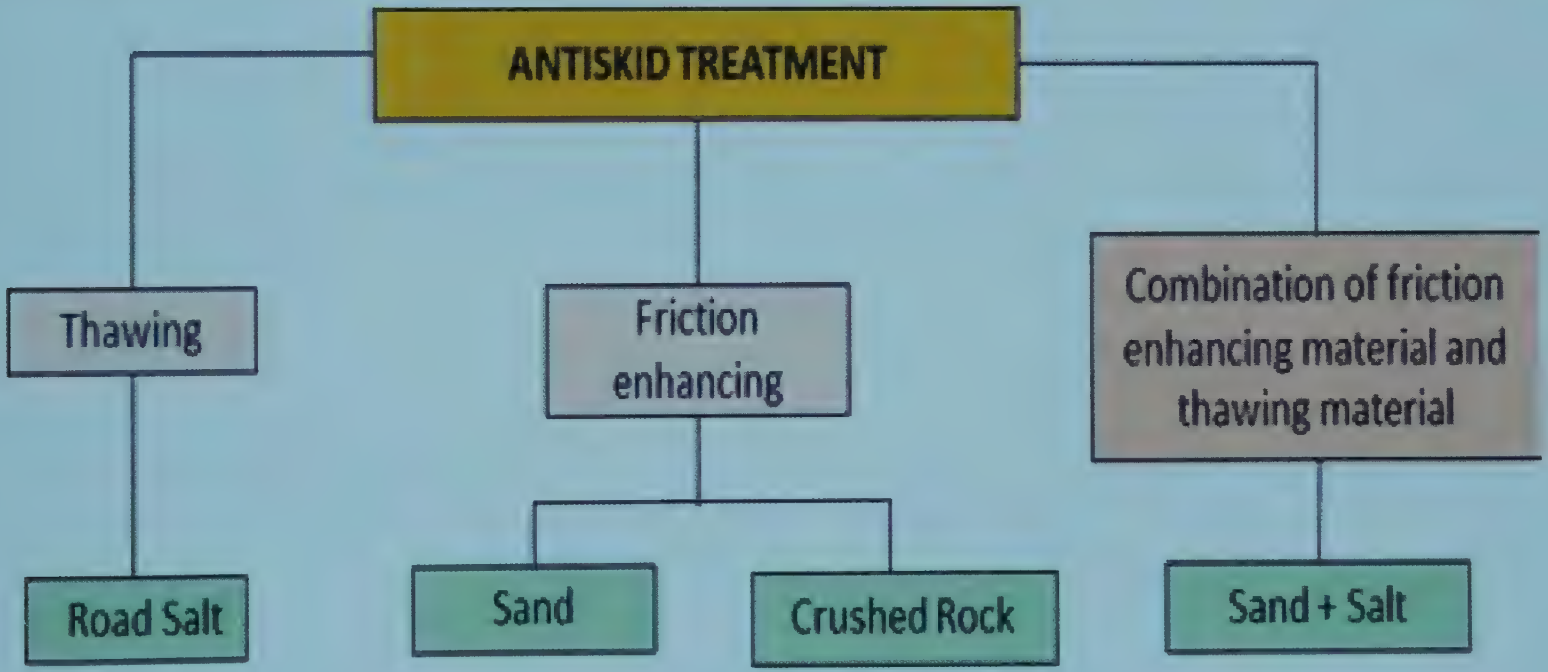


Fig. 6.13 Brief of Anti-Skid Treatment

6.6.9.6 *Environmental Impact*

Before applying any surface treatment, the environmental impact of the chemical must be studied in detail while considering the de-icing measures.

Chemicals (like Nacl) may react with infrastructure, the environment, and vehicles. Chlorides corrode steel and aluminum in reinforced concrete, structures, and vehicles. Acetates can cause asphalt stripping, weakening the bond between asphalt binder and aggregate.

Sand and grit can clog pavement joints and cracks, preventing pavement from expanding in the summer and increasing stress in the pavement.

Salts can be toxic to plants and aquatic life, including the trees lining the side of the roads. Sand can alter aquatic habitats where roads are near streams and lakes. Acetates can reduce oxygen levels in smaller water bodies, stressing aquatic animal life. Sand can be ground by tires into very fine particulate matter and become airborne, contributing to air pollution. Ground water in those areas must be adequately monitored and alternative green sources of de-icing chemicals may continuously be ventured.

6.7 Snow Clearance Operation

Snow clearance can be broadly classified into two types viz:

i. Continuous snow clearance in winter and part of summer which involves clearance of snow as and when it occurs is called winter snow clearance.

ii. Summer snow clearance which commences when the snow precipitation is over, and the total accumulated snow of the season is tackled in one operation

6.7.1 *Continuous Snow Clearance*

It is easy to clear freshly fallen snow by appropriate equipment like snow cutter upto a depth of less than 1 m provided there are no repeated snowfall, thereby giving adequate time for clearing all the fresh snow before the occurrence of the next snowfall. Roads below 3000 m falling in the snow belt can be kept open by continuous snow clearance using appropriate equipment.

Light dry snow is of little concern, but wet snow with heavy winds is a problem which results in dangerous conditions if not properly tackled. Wet snow under traffic, packed on the pavements and particularly if followed by a drop in temperature, can create very dangerous conditions. The best method of preventing the packing of wet snow is to have a large fleet of light, high speed, straight blade snow ploughs available. These ploughs should be started with the storm and kept working till the storm ends and the pavements are clear or until the snow gets so deep that snow ploughs cannot handle the situation.

6.7.1.1 Packed Snow and Icing problems

Packed snow forms when fresh snow is not cleared immediately, and the ploughs cannot keep ahead of the storm. Curves, hill sections, highway intersections and icing prone stretches, should be covered with a chemically treated abrasive material like sand or small chips. If the traffic is sufficiently heavy to warrant it, the entire road should be treated with abrasives. This type of work should be continuous during winter months. Application of abrasive material either alone or in combination with calcium or sodium chloride should be undertaken for treating icy pavements. The pavement should be treated whenever slippery conditions exists. The treatment procedure is given in para 6.6.

6.7.2 *Summer Snow Clearance*

In higher reaches of the great Himalayan ranges which are distinct snow belts, especially in the Western Himalayas, the intensity and periodicity of snowfall combined with avalanche activity and icing problems make it almost impossible to undertake snow clearance operations continuously. The snow, perforce, will have to be allowed to accumulate during winter months and in such cases the road sector has to be closed during winter months. The compacted snow on the road at places will be of the order of 10 to 12 m and at major avalanche sites this may exceed 30 m.

6.7.2.1 *Organization*

Despite the fact that summer snow clearance operation is mostly based on machines, adequate manpower is essential for various allied tasks like deicing, maintenance of the cleared road, cutting of rolled down trees, blasting of boulders brought by avalanches, launching of equipment bridges, carriage of stores, etc.

6.7.2.2 *Sequence of summer snow clearance operation*

Because the entire road is covered under a thick blanket of snow, it is a difficult job to trace the road alignment, though the snow markers erected specifically for this purpose do help. At times the snow markers get burned or unrooted. At many places, huge avalanches occur making it difficult to locate the road. If the snow clearance operation is commenced without locating the road this can lead to disaster. Therefore, it is of utmost importance to identify and mark the road alignment. Firstly, the road alignment should be marked with the help of prismatic compass and levelling instruments based on survey charts of the road. The help of snow marker should also be taken. The recce party with prismatic compass, levelling instrument and rolls of magnetic bearing charts mark the road alignment, with pegs/local material followed by tracked dozers.

Once the road alignment is identified and marked by the reconnaissance party, a dozer should be deployed first to make a breakthrough for the snow cutter and other tractor to follow the leading crawler tractor cuts the snow and makes the path for itself. The distance between tractors is kept 50 to 200 m depending upon site conditions. Where hard snow is encountered, it should be tackled by the crawler tractor. In this manner except for last 5 to 10 cm, the snow clearance is done by a combination of dozers and snow cutter. The remaining 5 to 10 cm of snow on the road surface should not be cleared by the crawler tractors to minimise damage to surface. This should be cleared by motor grader or manually or allowed to melt away. One snow cutter and a crawler tractor should follow in the rear to widen the cleared portion and to dear any snow drift or avalanche which may occur.

6.7.2.3 *Clearance of overhanging snow*

Whenever deep box cuts of snow are involved; the snow should initially be cut in a half tunnel pattern and subsequently these masses of overhanging and unsupported snow should be removed. Resorting to blasting is not desirable as this may trigger avalanche.

6.7.2.4 *Precautions*

When snow clearance operation is in progress the following precautions should be taken to ensure safety of men and machines. All men and machines should be deployed in a dispersed manner to guard against avalanches. At the end of the day, the machines should be parked at places free of likely avalanches. A sentry with a whistle should he detailed and located at a vantage point to give early warning of avalanches, All machines parked for the night should be covered with tarpaulins and other protective measures taken, During snow clearance operation an ambulance along with nursing assistant and first aid, should he available at site.

All workers should wear sun goggles as protection of eyes against glare of sunshine, adding anti-freeze chemicals to radiator water, use of winter grade diesel, draining radiators in the night are some methods to keep vehicles/equipment's in running order.

6.7.2.5 *Communications*

It is necessary that parties engaged in snow clearance are in communication with their main camp and the main camp in turn is in contact with their HQ. For this, short range walkie-talkie, wireless sets for local contacts and wireless radio sets for long range communications are essential.

6.7.3 *Road Maintenance Subsequent to Snow Clearance*

After snow clearance, enormous maintenance efforts are required to make the road traffic worthy. Road maintenance parties should follow immediately behind the snow clearance teams. The damage done by snow and avalanches to the drainage system should be restored on highest priority. The most important and immediate problem is the control of snow melt water on the road surface. A party should be detailed to control this water by diverting it to flow across the road at suitable intervals and also to clear the existing drains and culverts. The maintenance team should repair the following damages:

- All drains and culverts
- Pothole repairs
- Repair of damaged protective works like retaining wall, etc.
- Km stone and road signs should be repaired or replaced as necessary.
- Road formation should be repaired where damaged by avalanches.

After the snow clearance on the road, the snow on hill slopes melt and may cause slides. Also, the rivers flooded with snow melt water can cause toe erosion. Machines should be kept ready at vulnerable points to tackle these expeditiously.

6.8 Advance Planning Action for Snow Clearance

6.8.1 *General*

Meticulous advance planning and preparations are required to be done with the greatest care so that snow clearance operations do not get hampered and delays are minimised. Careful and detailed planning for the use of labour and equipment's during snowstorms and avalanche activity is necessary for successful results. The experience, ability and dependability of all men, types and adaptability of all available equipment's and finally the type and relative importance of the roads to be cleared during the storm must be considered. The plan should assign adequate equipment, well-manned, to the most important specific sections of the road without overlooking the other sectors on the road and keeping in view the vagaries of the snowstorm. During snow clearance season the men should be kept alert at all times and should be ready to undertake snow clearance immediately on occurrence.

6.8.2 *Snow markers*

The function of snow marker is to indicate the location of the road and depth of snow to the snow clearance team. A snow marker is a 50 mm dia. 3 to 5 m long Glass Fibre Rod or GI Pipe, graduated at 1.0 m intervals filled with concrete and erected on the Valley side with proper foundation. It is essential to check all the snow markers before the closure of road. A typical sketch of Snow Marker is shown in **Fig 6.14.**

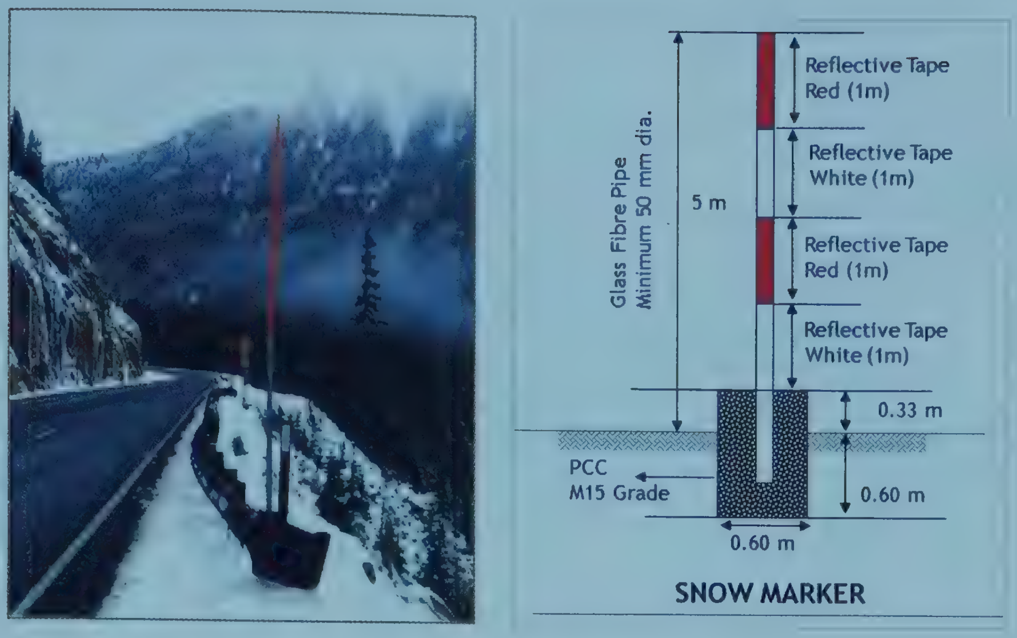


Fig. 6.14 Snow Marker

6.8.3 *Equipment*

It is essential that appropriate type of equipment's for snow clearance are positioned at the appropriate locations and their mechanical conditions checked before they are positioned at site. The equipment's should be in perfect working condition. The locations where these equipment's are required to be positioned should be so selected that they are safe, secure and clearly away from avalanche prone areas. Adequate stock of spares and a team of well-trained mechanics for the periodical maintenance of the equipment both during the idle period as well as during the operation should be positioned at centrally located camps in the sector, close to the location of the equipment. Adequate quantity of the right type of fuel and starting aids should also be stocked in the respective camps.

6.8.4 *Manpower*

The main aspects to be borne in mind regarding manpower are:

- These men should be physically robust and mentally alert, preferably of a lower age group.
- Adequate number of men to work with the equipment and for essential administrative duties should he positioned. At appropriate locations well before onset of winter.
- Suitable shelter with heating and warming arrangements, adequate food, clothing and medicines, etc. should be available at the various camps before deployment of the men,
- Proper intercommunication by wireless set between the sectors and HQ should he ensured.
- Suitable rescue/recovery posts should be established.
- Air sorties for mail, evacuation of casualties, and supply of rations, spares and conveyance of personnel should be made available as a routine/ on call service so that personnel have high morale.
- Essential recreational facilities should be provided

- The men should be acclimatized to work in high altitude and should be given adequate winter and snow clothing and trained to take precautions against likely adverse effects on them.

6.9 Snow Clearance Equipment

6.9.1 *General*

There is almost 10% decrease in efficiency of mechanical equipment for every 1000 m above mean sea level. Clearance machinery now in service in the country, is mostly imported equipment, mainly of German, Swiss and Canadian origin. There is a need to indigenize at least certain assemblies. Some equipment are shown in **Fig. 6.17** for reference.

6.9.2 *Effects, of Cold on Mechanical Equipment's and Counter Measures*

Metal under very low temperature will develop brittleness and the stressed parts and welds tend to fracture under impact. The adverse effect of this brittleness is particularly on blades and cutting edges of dozers, bucket fingers of loaders arid external moving parts and snow cutters. Cold also causes loosening of many parts such as master pins, cap screws and nuts etc. Rubber hoses, fan belts, hydraulic pipes, tyres, etc. are liable to harden and crack at low temperatures. Seals also harden causing stiff operation and failure leading to leakages. Insulation of electric cable may fail. Springs develop fatigue and lose tension. Wheeled machines become immobilized by soft snow of more than 30 cm and hence tracked machines are more suitable. Suitable shelters should be provided to machines. All plants should have heated cabins for efficient operation. The efficiency of the plant operator under exposed conditions may be as low as 35% whereas in a closed well heated cabin it could be as high as 75%. Snow clearance equipment can be broadly classified as snow removal machine and spreading machines. Snow removal machines can be further classified as blade ploughs and rotary ploughs.

6.9.3 *Crawler Tractor (Blade Plough)*

For heavy snow clearance operations, the blade plough dozer is the most suitable equipment **(Fig. 6.15).** Its advantages are:

- It can tackle any depth of snow.

  It is a tracked dozer and, therefore, can transmit considerable tractive force without slipping on snowcat has good manoeuvrability and turning radius especially suitable for restricted location.

- Presence of rock pieces and boulders in the snow does not damage or affect its performance and it is especially suitable for clearance avalanche debris.

- It can tackle hard snow except frozen icy smooth surfaces where it tends to slip. Its output varies from 1000-2000 tonne per day depending upon the varying site conditions.

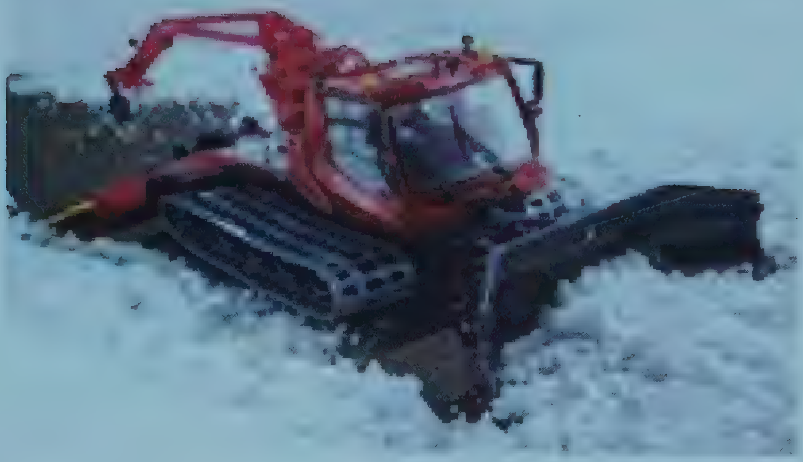


Fig 6.15 Crawler Tractor

Precautions: Since it is tracked, it can damage the pavement if sufficient precautions are not taken during snow clearance. Normally 15 cm to 25 cm snow is left uncleared below its track to avoid damage to the pavement. The residual snow can be cleared manually.

6.9.4 *Rotary Snow Plough or Cutter*

This is a versatile snow clearance equipment **(Fig. 6.16)**. Its advantages are:

- It can tackle upto 3 metres of standing snow.
- Its output is nearly 1000 MT per hour on soft snow.
- It has good mobility and can be moved to the site quickly.
- Being mounted on pneumatic wheels, it does not damage the pavement.
- The rotary head can be adjusted so that it does not leave more than 5-10 cm snow on the surface.

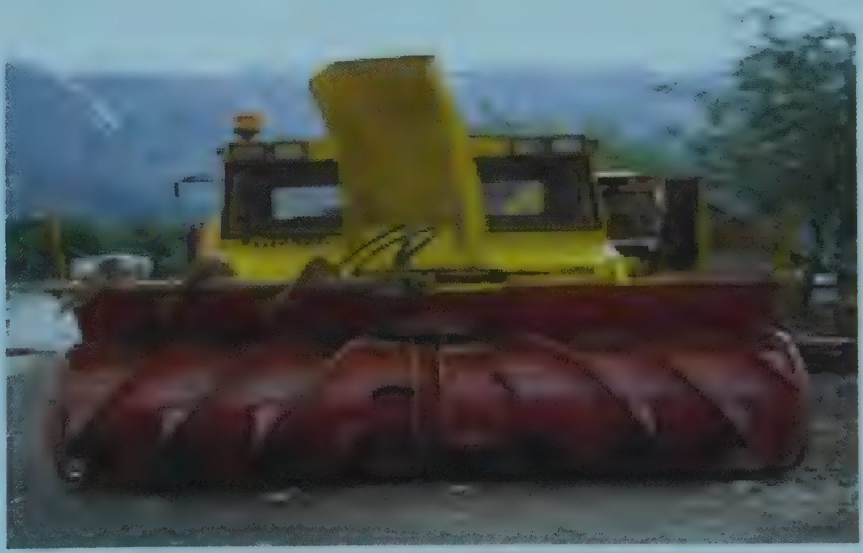


Fig 6.16 Rotary Plough Cutter

Precautions: It tends to slip on ice even with non-skid chain.

It can only be used in conjunction with dozer on heavy snow clearance. It can also damage the wearing course if not properly operated.

6.9.5 *Wheeled Dozers (Blade Plough)*

Wheeled dozers are useful for fresh light snow clearance.

Non-rotary snow plough: Non-rotary snow plough with different types of blades attached to a separate prime mover or to the normal vehicles and snow sweepers are used for clearance operations in fresh snow with light precipitation.

6.9.6 *Drag Scrapers*

A triangular metal frame of sides about 2.5 M long with rubber padding dragged by a load carrier vehicle can be used for clearing residual snow on the road after clearance by snow cutters, with a reasonable degree of success.

6.9.7 *Spreading Machines*

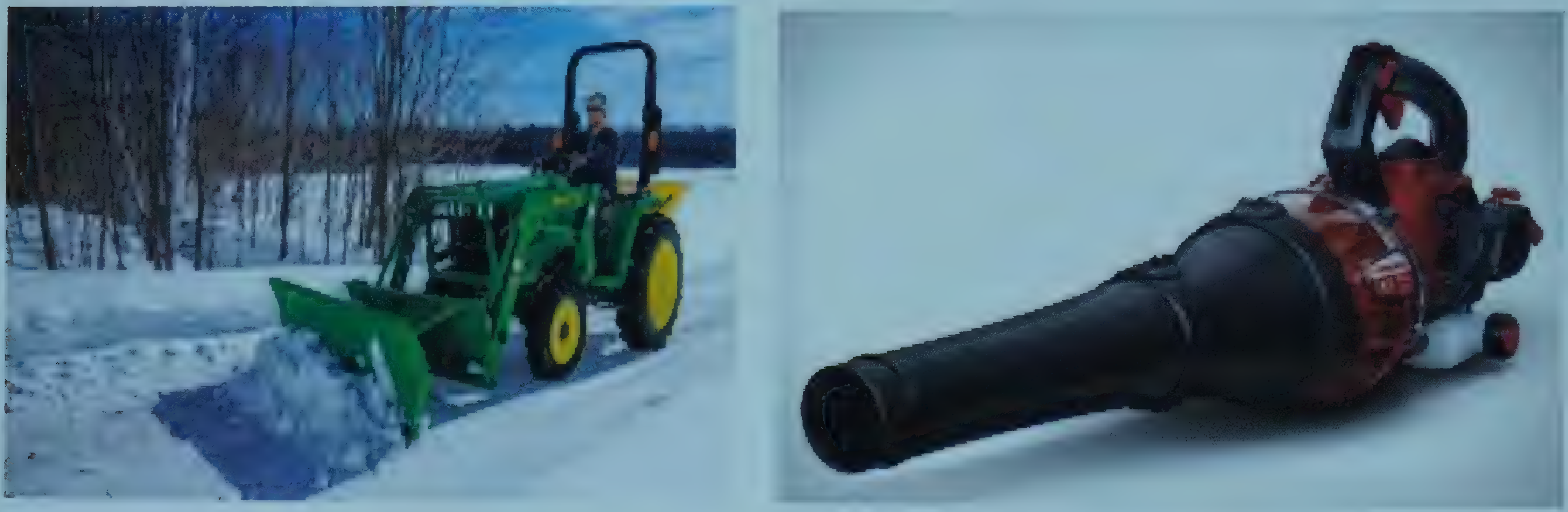
These machines are used for spreading, gritting materials and deicing salts/chemicals on the roads.

6.9.8 *Space Heater*

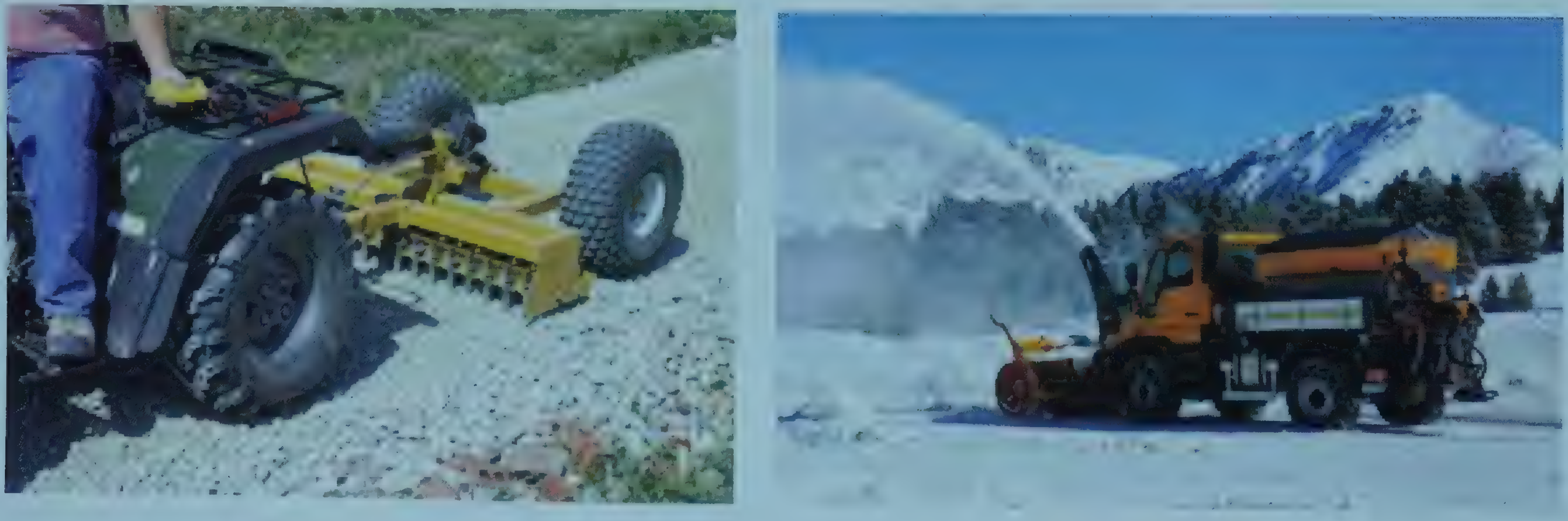
These are designed to blow a hot blast of air. Before starting engines in sub-zero temperatures hot blast of air is blown on engines so as to loosen the bearings for easy starting. It is also useful for changing engine oil in winter under low temperatures and for repairing machines in winter.

6.9.9 *Slave Starter*

These are used for charging batteries which frequently get discharged due to very low temperatures.



Wheel Dozer **Space Heater**



Drag Scrapper **Snow Spreader**

Fig.6.17 Photographs of some Snow Clearance Equipment

6.10 General Specification of Materials which may be used for construction of structures in formation zone, middle zone and run-out zone are indicated in **Appendix - 6.1, 6.2, 6.3 & 6.4**

7. ROAD CONSTRUCTION TOOLS, PLANTS AND EQUIPMENT

7.1 General

7.1.1 The nation today is poised for an infrastructural revolution especially in the hilly regions. The necessity is felt for affording all weather connectivity for the people of North and North East regions and for security imperatives. (IRC:43, IRC:72, IRC:90, IRC:126, IRC:SP:86, IRC:SP:96)

7.1.2 Construction of roads, bridges, tunnels and other allied works in hills require mechanization due to the following factors:

a) Non-availability of adequate local labour

b) Difficult terrain and remoteness

c) Severe climatic conditions

d) Requirement of special and innovative specifications due to increasing traffic and environmental considerations.

7.1.3 Due to severe climatic conditions in most of the hilly areas, the fair weather period available for work is also short. Some of the hilly areas have heavy rainfall or snow-fall for major part of the year. Since the time available for work is very limited, mechanisation is inescapable to achieve high productivity during the available short (working window) time. Heightened awareness and regulations for Environmental considerations has further necessitated mechanized approaches for activities like muck dumping, running environment friendly mix plants etc.

7.1.4 A suitable blend of machines and manual labour, depending upon local conditions and nature of activity, is generally considered most appropriate for hill road construction. The proportion is decided keeping in view the output norms of men and machines and fair weather period available for construction activity in different hilly areas. The average output norms of labour for major construction activities are given in MoRTH Standard Data Book for Analysis of Rates for Hilly Terrain Volume II (Second Revision-2019). The norms for machines may be worked out based on the actual output claimed by manufacturer. Number of machines to be employed shall be calculated based on quantum of work, desired project completion time and specific site requirements. The norms vary inter-alia with the terrain climatic conditions, skill of labour and site specific conditions. In case of machines, output norms further vary with make, model and mechanical conditions of machines and degree of complementing/balancing resources available. The labour norms are only a rough guide for altitudes up to 2100 meters. The actual output on site should be deduced after deliberating upon site specific performance factors.

7.1.5 For works at altitudes exceeding 2100 meters a reduction factor has to be applied as efficiency gets reduced due to high altitude effect. Considering loss of output of men and machines above 2100 meters altitude the extra efforts required upto 5700 meters altitude is given in **Table 7.1**.

Table 7.1 Extra efforts required in respect of Men and Machinery for Altitude above 2100m

Altitude in Metres above MSL	Extra Efforts in % (Personnel)	Extra Effort in % (Machines)
2100-2400	7	3
2401-2700	15	6
2701-3000	25	9
3001-3300	32	12
3301-3600	48	15
3601-3900	66	18
3901-4200	86	21
4201-4500	108	24
4501-4800	132	27
4801-5100	156	30
5101-5400	180	33
5401-5700	204	36

7.1.6 The fair weather working period for hilly region during rainy reason and those remaining in the heavy snow fall for a month or more in a year are generally assigned as under;

(a) Heavy rain fall areas (all North Eastern States) - 5 / 6 months in a year.

(b) Heavy snow fall areas (all North, North-Western and north-Earthen Himalayas) - 4 / 5 months in a year.

(c) The weather in most of the areas follows a cycle. Thus fair weather period varies from year to year as well. The length of the fair weather period shown above is only an indicative average period.

7.2 Construction Methods and Tools

7.2.1 Road construction work is divided into the following major phases:

a) Road alignment finalization

b) Formation cutting/embankment

c) Protective and Drainage works

d) Pavement works

7.2.2 The requirement of tools, appliances and equipment required for a particular construction project has to be based on the plan of construction and phases of the project. Each activity requires a specific set of equipment and resource levelling must be adopted by following a proper construction planning practice so that all resources are optimally utilized and minimal idling is resorted to.

7.2.3 The description of tools and equipment is given in IRC publication "Handbook on Road Construction Machinery" of MoRTH, which may be referred for further details for choice of equipment. However the choice must always cater for site conditions. Factors like mobility, deploy-ability, and suitability for end use must be analyzed in detail to obtain maximum output at site.

7.2.4 It is desirable to have GPS enabled tracking system on important machineries used on the project site.

For proper and improved contract management, it is necessary to install GPS enabled tracking system on key machineries of contractor, which will be beneficial for the client as well as the contractor. This system will provide better transparency in the contract and will enhance the working relation between the client and the contractor.

7.3 General Factors affecting Output

7.3.1 The following factors affect output of machines

a) Work must be planned to avoid interference between machines e.g. between digging plant or grader and haulage vehicles.

b) Haulage and working routes must be planned and well maintained and traffic control arranged.

c) Mutual assistance e.g. push dozer and scrapers, must be organized.

d) Working down-grades increases output and upgrades reduces same.

e) Time spent on proper servicing is less than time lost through breakdowns due to neglect.

7.3.2 *Balanced Output*

The effective output of a machine is often dependent either upon the material made available to it by other piece of equipment or upon the rate of removal of the material which it produces by itself. For example, material such as shale may have to be ripped with a ripper or blasted with explosives before it can be broken. If it is then loaded by a power shovel into dumpers or trucks for transport to a distant site, the overall output will depend not only upon the capacity of the power shovel but also upon the rate of loosening and number of haulage vehicles deployed. In any individual operation, therefore, it is important to ensure that a properly balanced set of equipment and labour is provided.

7.4 Optimum Output

7.4.1 Correct selection of equipment and tools, correct techniques of operation, balanced set of equipment and regular maintenance can give optimum and economical outputs from construction machinery.

7.4.2 Selection of right set of equipment at the right phase of the project with the right supporting machinery will ensure optimal output and accelerated project completion.

7.4.3 Planning of construction schedule should always include the equipment induction plan based on principles of resource leveling.

7.4.4 In high altitude and remote areas due to paucity of immediate repair cover and spares redundancy of equipment must be maintained.

8. MAINTENANCE OF HILL ROADS

8.1 General

8.1.1 A road is designed and constructed to cater to a comfortable, unhindered and safe passage of users with designated design speed. Thus the road user and vehicle which compose the traffic is the most important consideration as soon as a road is opened to traffic. All facilities and amenities will have to be provided to ensure smooth traffic consisting of a well-maintained road with information on its condition, warnings and caution, road side amenities etc. This has to be ensured and assured on a regular and sustained basis which needs an effective and planned maintenance programmed and its efficient implementation. On hill roads all above aspects become more pronounced due to terrain, topographic and climatic conditions of hill/mountain regions.

8.1.2 Maintenance of hill roads involves a variety of operations from planning, programming and scheduling to actual implementation on ground. The aim should be to keep the road surface and appurtenances in good order, extend life of the road assets and to minimize hindrance to traffic. This will include identification of defects and remedial measures which involves launching an effective management system. In broad terms, maintenance activity will include normal maintenance, periodic renewal, special repairs, emergent repairs and slide/snow clearance operations.

8.2 Basic Maintenance Objectives and Policies

8.2.1 The basic objectives of maintenance function are to maintain and operate the highway system in a manner such that comfort and safety are afforded to public. It is also aimed that investment, aesthetics and compatibility of road system including environment are preserved and resources are used economically. Each of these objectives is elaborated in following paras.

(a) **Service to Road Users:** The road system should be maintained adequately at all times to ensure safe and convenient travel, considering the density and nature of traffic being served. Emergent conditions may develop from time to time, adversely affecting safe and convenient travel which should be attended to promptly. Persons dealing with maintenance of traffic should be on call at all times and be ready to be of service in effective use of the roads. Such emergency detachments must be maintained and remain active in vicinity of all registered troubled spots.

(b) **Preservation of Investment:** It is the objective, as far as possible, to maintain all roads, bridges, tunnels and appurtenances in originally constructed or subsequently improved condition, and perform works of such conclusive and restorative nature to ensure preserving that the investment of public funds in each road.

(c) **Preventive Maintenance:** Maintenance of a clearly preventive nature (as opposed to waiting until correction is required) shall be performed by operating units. Planned work of a restorative nature (maintenance, replacements or reconstruction) which will be done in a reasonable length of time, shall be the only reason for deferring routine maintenance. For preventive maintenance, It is preferred that the stretch should on the contract maintenance with due provision of all required maintenance activities. In case of departmental maintenance, there shall be a maintenance gang with required infrastructure and which shall be available with the maintenance agency round the year for maintenance of single/double lane DNR/SH/NH, as per details given in **Table 8.1**.

Table 8.1 Tentative Maintenance Detachment for every 30 km

Requirement	**Nos. /Qty.**	**Remarks**
	Manpower	
Junior engineer	01 No.	Minimum Qualification - Diploma in Civil Engg
Pioneers	02 Nos.	Permanent Govt Employees
Equipment Operators	02 Nos.	Permanent Govt Employees/ Casually Paid
Drivers	04 Nos.	Permanent Govt Employees/ Casually Paid
Labour	75 Nos.	Casually Paid
	Equipment	
Road Roller Vibratory	01 No.	
Tipper/Dumper / Load Carrier	03 No.	One covered vehicle for transport of labour
Spot Mix Plant	01 No.	6 Tonnes per hr
Concrete mixer	01 No.	4 cum per hr
Excavator Back Hoe	01 No.	Addl 01 ft wide Bucket for drain Clearance
2/2.5 Tonne Pickup vehicle	01 No.	
	Stores	
Cement	25 MT	
Bitumen	75 MT	
Explosive	01 MT	
Paint	100 Ltr.	
Lime	05 MT	
Inter Linked Chain	05 MT	
Sign Boards	Replace 10 % / year	
Crash Barriers	Replace 10 % / year	
Cat Eyes	Replace 25% / year	
Fuel	5000 Ltr. HSD	10 % Oils and Lubricants
	Tools	
Pickaxe	20 No.	Replace 10 % / year
Crowbar	10 No.	Replace 10 % / year
Shovels	50 No.	Replace 10 % / year
Hedge trimmers	10 No.	Replace 10 % / year
Misc Mason / Carpenter Tools	Rs 1 lac / yr	
	Accommodation	
Govt	10 persons	Adequate Amenities
Labour	75 persons	Adequate Amenities
Cook House	01	
Maintenance	05 % of cost of Accommodation / Year duly enhanced with Cost Index	

***Note: -** Additional Funds for Special repairs, rain/flood damage repairs shall be required over and above the resources mentioned in the Table. These repairs should include repair of bridges, maintenance of slopes and dedicated efforts required for attending to troubled spots along the road alignment. These funds should be demanded every financial year as per actual ground requirements. For lower standard roads similar detachment and funds are recommended for every 40 Km.*

*For works at altitudes exceeding 2100 mtrs. and upto 5700 mtrs., the manpower and machinery will be correspondingly increased in view of reduction in efficiency as given in **Table 7.1** due to high altitude effect. In addition required numbers of snow cutters/snow clearance machines shall be stationed/ provided.*

(d) **Environmental considerations:** Maintenance operations should be performed in such a manner as to preserve or enhance the compatibility of the road system with environment. The maintenance of roadside shall be directed towards the preservation or enhancement of the natural beauty of the road land.

8.3 Performance of a Hill Road - Governing Factors

8.3.1 The performance of a hill road vis-a-vis traffic comfort is dependent mainly on the following:

a) Road geometrics

Road and carriageway width, radii of curves, widening at curves, gradients. summit and valley curves. sight distance, super-elevation/camber/cross-fall etc.

b) Efficiency of drainage

c) Riding surface and its conditions

d) Unstable areas, slide-prone areas and areas susceptible to erosion

e) Information system/signs

f) Climatic conditions

The above factors have therefore, a prominent place of consideration in the maintenance efforts for the road.

8.4 Components of Maintenance Activities

8.4.1 Routine/Regular Maintenance activities on hill roads will consist of the following:-

a) Routine maintenance and upkeep of road component as under:-

i. Road pavement and shoulders including repairs of potholes, ruts etc.

ii. Drainage system consisting of side drains, catch-water drains, sub-surface drains.

iii. Culverts, bridges, causeways etc.

iv. Structures like retaining walls, breast walls, parapets, railings, toe walls, check walls, river training structures, etc. .

v. Km. stones, road signs, boundary pillars, etc. including replacement when required.

vi. Roadside amenities like Traffic Aid Pots, Emergency Medical services, all communication systems installed on the stretch, rest houses, inspection bungalows, residential and office/storage accommodation, gang huts, etc.

vii. Roadside arboriculture, including development of scenic spots.

b) Clearance of land-slides/slips caused by rains or other natural causes.

c) Snow clearance to keep road open to traffic.

d) Providing adequate information, warning, etc. to the rood user on the road condition.

e) Collection of traffic data for forecasting future trends to plan upgrading the pavement composition and if so necessary, the road standards.

8.4.2. *Special Repairs/Flood Damage Repairs*

Repairs of damages caused by floods, rains or other natural calamities that are beyond scope of ordinary repairs/routine maintenance come under this category and are normally executed as original job. Funds for these works may be from additional maintenance grant or capital works grant as decided by approving authority.

8.4.3 *Emergent Repairs*

On hill roads, it may often become necessary to take up on immediate basis work of emergent nature like rebuilding structures; construction of bridges in replacement of washed away bridges, cutting a new formation in place of breached/washed off road stretch, diversions, etc., to restore traffic or to warn off danger to life/property. Such works may have to be commenced by field executive in anticipation of formal sanctions based on urgency as these works do not come under purview of normal maintenance or grant thereof. However, this work is considered under 'Maintenance' as this is a work to ensure continued traffic ability of the road and special maintenance grant is allotted for this purpose.

8.4.4 *Periodic Renewal*

This refers to periodic renewal of wearing course of the carriageway based on guidelines on life cycle and specifications adopted for the Hill Road. In the case of gravelled or metalled or earthen roads, the renewal of the top layer is not normally done periodically but repairs carried out regularly under ordinary repairs. Where quantum of work is high due to damages by natural causes, these are treated as special repairs.

8.5 Planning and Financing

8.5.1 *Inventory of road*

The first step to planning of maintenance operation and for deciding required finance is evaluation of the existing road in terms of its physical condition, structural capacity and surface profile (roughness), etc. For this purpose, basic road inventory containing all details of the existing road should be available. The following details are required to have a complete inventory.

8.5.1.1 Strip Maps

Strip maps where required of a particular section of the road must have the following details as given in **Fig. 8.1.**

a) Kilometrage, altitude, road geometrics viz. road width, steep gradients, if any, culverts with brief particulars, crossings, etc.

b) Availability of materials and location of quarries.

c) Availability of T & P, existence of stores and departmental workshops, gang huts, etc.

d) Any other feature such as sections which require special attention to substandard geometrics, e.g. inadequate sight distance, horizontal or vertical alignment, narrow width, inadequate super elevation, weak bridges etc.

e) Broad soil types, hill slopes and terrain data.

f) Unstable/slide - prone area, snow/avalanche/glacier area

8.5.1.2 Surface History

Surface history of the road should be compiled in the format given in **Appendix 8.1**. It should contain the summary of information available in the road register maintained on the prescribed lines. The information should be as accurate as possible and collected from the available records. This will help in deciding when renewal coat due with its period in a particular stretch of road.

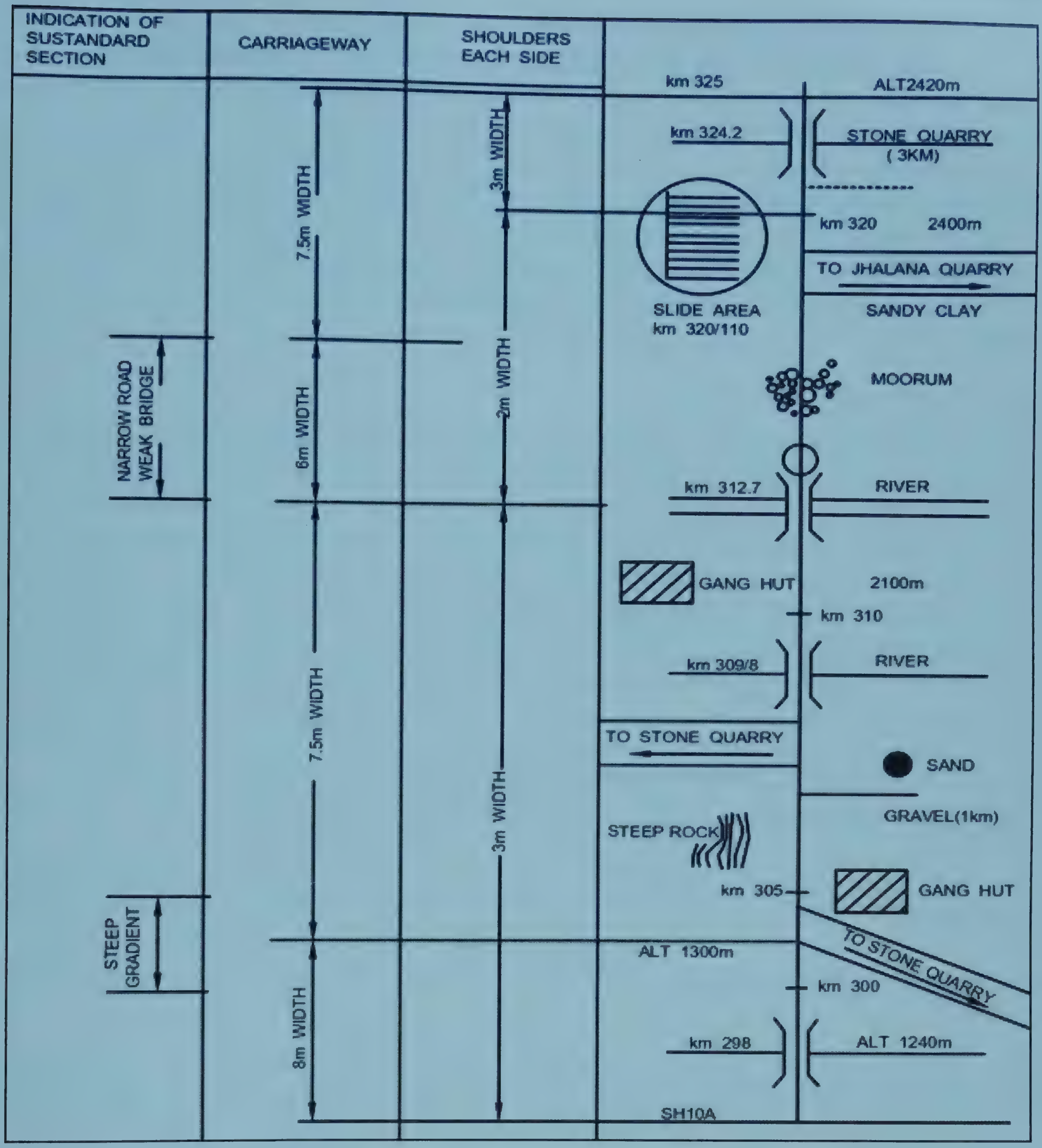

INDICATION OF SUSTANDARD SECTION
CARRIAGEWAY
SHOULDERS EACH SIDE
km 325
ALT2420m
km 324.2
STONE QUARRY (3KM)
3m WIDTH
7.5m WIDTH
km 320
2400m
TO JHALANA QUARRY
SLIDE AREA km 320/110
SANDY CLAY
NARROW ROAD WEAK BRIDGE
6m WIDTH
2m WIDTH
MOORUM
km 312.7
RIVER
GANG HUT
2100m
km 310
km 309/8
RIVER
TO STONE QUARRY
SAND
7.5m WIDTH
3m WIDTH
GRAVEL(1km)
STEEP ROCK
km 305
GANG HUT
STEEP GRADIENT
ALT 1300m
TO STONE QUARRY
km 300
8m WIDTH
km 298
ALT 1240m
SH10A

Fig. 8.1. Typ. Strip Chart (Road Inventory Chart)

8.5.2 *Condition Survey*

8.5.2.1 When all the Inventory of the road is available, condition survey can be carried out:

a) By a visual inspection

b) By mechanical evaluation

Condition survey by visual inspection/ assessment of the pavement cover the type, magnitude and location of the deficiency or distress. Necessary information about the routine maintenance can be had by simply going along the road and comparing past and present state and arriving at the likely causes of distress.

8.5.2.2 Pavement surface evaluation based on surface condition (cracking, patching), riding quality (i.e. road roughness) and skid resistance would form basis for taking periodic maintenance decisions. Condition survey at fixed frequency is necessary for determining periodic renewal requirements, long term maintenance strategy and need for up gradation. The condition survey may also be conducted for each stretch of the road as frequently as the situation warrants. Generally, the condition survey is carried out from a Network Survey vehicle travelling at a slow speed supplemented by inspection of more critical spots on foot once in six months. The data collected should be recorded methodically kilometre-wise. While carrying out inspections, the check list of items given in **Appendix – 8.1** .The findings of condition survey should be recorded in a suitable format.

8.5.3 *Programming and Planning*

8.5.3.1 Based on the condition evaluation, the causes for the various defects observed should be examined in detail and a decision taken whether to initiate a particular maintenance activity, or to go in for more detailed investigations to determine the maintenance/rehabilitation needs precisely. Whenever distress on the pavement has reached the stage which affects the smooth operation of traffic, it should be rectified straightway. For other defects like cracking, raveling etc. the optimal strategy should be determined having regard to the various factors involved and a decision taken whether to go in for measures like seal/renewal coat or to strengthen/reconstruct the pavement. If the latter appears necessary, further investigations about structural deficiencies must be taken up. In other words, the planning of the various maintenance operations should be coordinated and looked upon as a total system rather than each activity being considered in isolation. The criteria for maintenance priorities/rehabilitation needs would be as per the guidelines given under the heading “Maintenance Criteria” **in para 8.7.**

8.5.3.2 Once the overall maintenance plan has been drawn up, attention should be given to the proper organization and management of the whole programme including deployment of various resources i.e. men, materials and equipment, in an efficient manner. For each maintenance activity, the work at site should be carefully controlled so that the optimum output and quality are achieved.

8.5.3.3 Annual calendar of road maintenance activities: The planning and programming of various major maintenance activities throughout the year should be done in advance keeping in view the climatic conditions and periods available for carrying out different activities. This calendar will help in planning the activities at the appropriate time.

8.5.4 *Scales of Maintenance*

8.5.4.1 Roads in hills are subject to vagaries of weather like heavy rain-fall, floods, land-slides, snowfall, breaches, etc. blocking road and compelling closure of road at times inspite of the desirable principle that a road is available for traffic all the time. Though the resources and financial outlay required for uninterrupted road availability may be disproportionately huge, (and even then an assurance of uninterrupted availability cannot be ensured at all times on a hill road) it is a practice to classify roads under different scales of maintenance depending (single/double lane District Roads/State/National Highways) on their importance. For day to day routine maintenance of hill roads a maintenance Contract (maintenance detachment/maintenance gang in case of departmental work) shall be kept operational at all times.

8.5.4.2 Roads in snow bound areas are so classified depending on intensity, quantum, and period of snow fall i.e. roads planned to be kept open throughout the year and those kept open only in summer months (i.e. closed in winter).

8.6 Inspection

8.6.1 Inspection should be carried out not only to check the condition of works but also for planning future strategies. Senior officers shall make it a point to note and communicate instructions to the subordinates. While on inspection, the senior officer shall go through the notes of junior colleagues and make suitable suggestions so that inspections are meaningful. Items required to be inspected are listed in the check list given at **Appendix 8.1.**

8.6.2 *Identification of defects*

It is important to identify and locate the defects of surface, shoulders, side drains and cross drainage during the inspection of the road by various officers. Reference should be made to IRC: 82 “Code of Practice for Maintenance of Bituminous Roads" to help in identifying the various surface defects such as bleeding, streaking, cracking, raveling, edge subsidence, edge fretting, rutting, shoving, potholes etc. Common defects and deficiencies of shoulders, side drains, cross drainage works, etc., have been indicated in a separate **para 8.8.7** under the heading “Maintenance of Drains, Cross Drainage Works, Shoulders and Slopes”. A suitable procedure shall be evolved for inspection and planning.

8.7 Maintenance Criteria

8.7.1 Once the inspection of road for condition survey has been carried out and its findings available, the priorities for the required maintenance operations are required to be fixed. These priorities are to be assigned judiciously looking to the urgency of the work. The urgency is governed by factors like;

a) Safe and unobstructed flow of traffic

b) Preservation of the assets in the form of roadway and its appurtenance and

c) Preventive maintenance to avoid any further deterioration.

8.7.1.1 Guidance regarding assignment of priorities is given in **Table 8.2**, which indicates the priorities for various operations broadly on the following principles:

a) Urgent for jobs requiring top priority

b) Special for jobs which are in next order of priority

c) Recurrent for jobs which occur recurrently and are next to special in order of priority and

d) Routine - for jobs which are to be attended to in a routine manner.

Table 8.2 Priorities for Maintenance

Feature 1	Criteria 2	Action 3	Priority 4
A. Features concerned with safety of traffic			
1. Landslides/slips	Any type of slip or slides blocking the road and affecting flow of traffic	Steps to be taken as given in Chapter 11 "Traffic Management" Slide to be cleared on top priority	Urgent
2. Snowfall/ Avalanche	Road affected by snowfall or avalanche activity, compelling suspension of traffic	To be cleared as per policy on road-open period in winter season for the road	Urgent
3. Major breaches in the roadway	Any type of breach which endangers safety of traffic and causes obstruction to flow of traffic	Steps to be taken as given in Chapter 11 "Traffic Management"	Urgent
4. Minor cuts, ruts or blockades	Cuts or blockades which do not completely obstruct the traffic but endanger safety of traffic	Blockades to be removed and the cuts repaired.	Urgent
5. Branches of trees of height less than 4.5 m over the roadway	Any kind	Branches to be cut in order of lower ones first	Special Attention
B. Carriageway and Crust conditions			
1. Cracking not accompanied by rutting	a) Cracking in local areas equal to or less than 25 per cent of the total area b) Cracking in large areas exceeding 25 per cent of the total area	a) Local sealing or filling of the cracks b) Binder @1.5 kg/m^2 of bitumen emulsion or 1 kg/m^2 of cutback for local sealing. c) Chippings (6-10 mm) for local surfacing repairs. Needs surfacing after local sealing	Routine Special Attention Special Attention
2. Stripping	a) In local areas exceeding 25 per cent of the total area b) In long areas exceeding 25 per cent of total area	Apply local sealing Apply surface dressing	Routine Special Attention

3. Bleeding	a) In local areas not exceeding 25 per cent of total area b) In local areas exceeding 25 per cent of total area	Spread and roll over 6 mm size aggregate, heated to 60°C Apply surface dressing	Routine Special Attention
4. Rutting	a) Less than 50 mm accompanied by cracking of less than or equal to 10 m/m² b) Less than 50 mm accompanied by cracking more than 10 m/m² c) More than 50 mm accompanied by cracking more than 10 m/m²	Apply coat @ 0.5 kg/m² and fill bituminous mix using a rake and leaving an excess thickness of about one third the depth of rut. Compact till surface is level and do local sealing of cracks. ---do--- With surface dressing over cracks. Overlay required	Routine Special Attention Work of original nature
5. Potholes	Potholes as soon as they occur	Local restoration by patching	Urgent
6. Reflection Cracks	a) Widely spaced cracks b) Closely spaced cracks	Seals Apply surface dressing	Recurrent Special Attention
7. Edge subsidence and rutting	Any extent	Patch road edge and repair shoulder	Recurrent
8. Defective camber	Any extent	Check and correct by reconstructing to proper camber profile	Special Attention
9. Undulations	Any extent	Investigate the cause and rectify	Special Attention
10. Loss of material from unpaved road	Any extent	Do re-gravelling	Special Attention
C. Shoulders, side drains, catch water drains, etc.			
1. Deformation or scour of shoulders	Any extent	Fill, compact and bring its surface to desired camber	Routine
2. Silting of Drains	Any extent	Clean out the drains	Routine
3. Damage or scouring of drains	Any extent	Reconstruct to adequate shape and size	Special Attention

D. Cross drainage works – causeways, culverts/minor bridges, equipment bridges			
1. Causeways a) Potholes in paved surface b) Erosion at inlet/ outlet c) Guide posts/Flood gauge missing	Any extent Any extent Any extent	Repair by filling Repair Repairs/Replace	Special Attention Special Attention Special Attention
2. Culverts a) Silting b) Erosion at inlet/ outlet c) Settlement cracks d)Settlement/ damage to chutes and Guides	Any extent Any extent Any extent Any extent	Desilting Repair Repair Repair/Rebuilding	Special Attention Special Attention Special Attention Special Attention
3. Equipment Based. a) Damage	Any extent	Repair	Urgent
E. Major bridges			
1. Damage to substructure including foundation	Any extent	Investigation and repairs	As per bridge maintenance and repair policy
2. Damage to superstructure including roadway	Any extent	Investigation and repairs	As per bridge maintenance and repair policy
F. Structures like retaining walls, breast walls, river training structures etc.			
1. Damaged Structures	Any extent	Repair	Urgent
2. Collapsed Structures	Any extent	Rebuilding	Urgent
G. Other works			
1. Road furniture and warning signs dirty or corroded or damaged/missing	Any extent	Clean and repair/replace	Routine
2. Missing road signs	Any extent	Fix new one	Special Attention

In case the road is breached or blocked, action as given in Chapter 11 “Traffic Management” should be taken

8.7.2 *Criteria for renewal*

The wearing course will need renewal periodically either as redoing the worn-off or distressed wearing course or to upgrade the same to superior specifications to cater to the increased traffic needs. The following criteria may be adopted in this regard:

a) Normally, the wearing surface will have a life cycle under design traffic conditions, weather conditions etc. Based on inspection and surveys of the condition of the surface, over a period of time and considering traffic/climatic conditions, normal life cycle for surface course should be arrived at, which can act as a guide. The rough life cycle for hill roads, is given in **Table 8.3** as a guide.

b) While the life cycle given above is a guide, there will be instances where the condition may not warrant renewal even if stipulated life has been achieved and may be deferred. There may also be cases where renewal may be required even before stipulated life. In such instances renewal shall be done before the stipulated period shown in table to prevent deterioration of the pavement and hazards to traffic.

c) When a road is due for renewal, it would be logical and rational to evaluate traffic volume and conditions and plan up-gradation of specifications of wearing course. If upgradation is necessary, design and specifications should be as per **Chapter 5 “Pavement Design”** for Hill Roads in respect of composition and specifications.

Table 8.3 Life Cycle in Years for Resurfacing/ Renewal Treatment

Condition	Periodicity for Resurfacing	Remarks
All flexible pavement constructed as per the design requirement	5 years	Resurfacing wearing course
For any renewal work of flexible pavement		
Traffic >1500 CVD	3 years	Resurfacing wearing course
Traffic 750-1500 CVD	4 years	Resurfacing wearing course
Traffic <750 CVD	5 years	Resurfacing wearing course
Roads having more than 30 days snowfall	3 years	Replace wearing course
Extraordinary damage to wearing surface	Rehabilitation/Resurfacing may be taken up based on recommendation of the Authority.	Under Flood damage/Heavy Rainfall Damage to wearing surface

Note:- Recycling of wearing course may be resorted to where technically feasible to reuse same aggregate for ensuring green construction practice.

8.7.2.1 It must always be borne in mind that if timely renewals and/or upgradations are neglected, the road condition is bound to deteriorate not only resulting in inconvenience to traffic but also in compromising safety and possible avoidable additional finances to restore normalcy.

8.8 Execution of Maintenance Operation

8.8.1 *Principles*

In the implementation of maintenance operations, the road user and personnel involved in the work should not be exposed to hazards. Besides, delay and inconvenience to the traffic, should be reduced to the minimum.

8.8.2 Traffic hazards and inconvenience can be minimized by use of temporary road signs and controlling/guiding of the traffic. While keeping in mind the positioning of road signs, the standard signs in good and clear condition should be displayed in a proper and standard layout, so as to give the drivers sufficient time to understand and read the information on the sign. The signs to be used should be as per IRC:67 "Code of Practice for Road Signs".

8.8.3 Maintenance operations at a time should be confined to small lengths, say 30 m, half the pavement width, leaving the other half for use by traffic. However, sometimes this may not be possible, and in such a case, maintenance work can be divided in the following four categories from the point of view of safety and traffic control:

a) Repairing the edges of the carriageway, shoulders, cleaning out drains, cutting grass etc. where carriageway is not affected.

b) Repairing the carriageway restricting the traffic.

c) While working on the centre line such as centre line marking/painting necessitating the traffic to use restricted width on either side.

d) Total closure of the road necessitating use of diversion due to widening/ reconstruction of an existing Cross Drainage work or construction of a new structure or due to breach or damage to existing road or Cross Drainage works or due to land-slides.

8.8.4 Procedure for various categories are given in succeeding paragraphs.

8.8.4.1 Works on edges and shoulders

Before starting the work, all warning signs should be installed in the following manner.

"MEN AT WORK" should be placed 200 m before approaching the work area and "RESTRICTION ENDS" sign should be displayed 200 m beyond the work area. When the work is completed, these signs should be removed in the reverse order."

8.8.4.2 Restricting the traffic

At times, the traffic is to be restricted only due to repairs being carried out such as major patch repairs, etc. The position of various cautionary and warning signs are illustrated in **Fig. 8.2** which are to be installed before start of the work in the following sequence:

i. "PEOPLE AT WORK" sign to be put up 200 m before approaching of work site.

ii. "NARROW ROAD AHEAD" should be at 100 m ahead of work area.

iii. "KEEP LEFT/RIGHT" sign to be placed at the commencement point of work and next to the barriers on either end of the work area.

iv. "BARRIERS" should be placed on both sides of the work area.

v. DRUM DELINEATOR as per IRC:79 should be placed at 10 m intervals for guiding the traffic. In the approaches these are to be kept in a tapered manner.

vi. "RESTRICTION ENDS" sign should be installed 200 m beyond the work area.

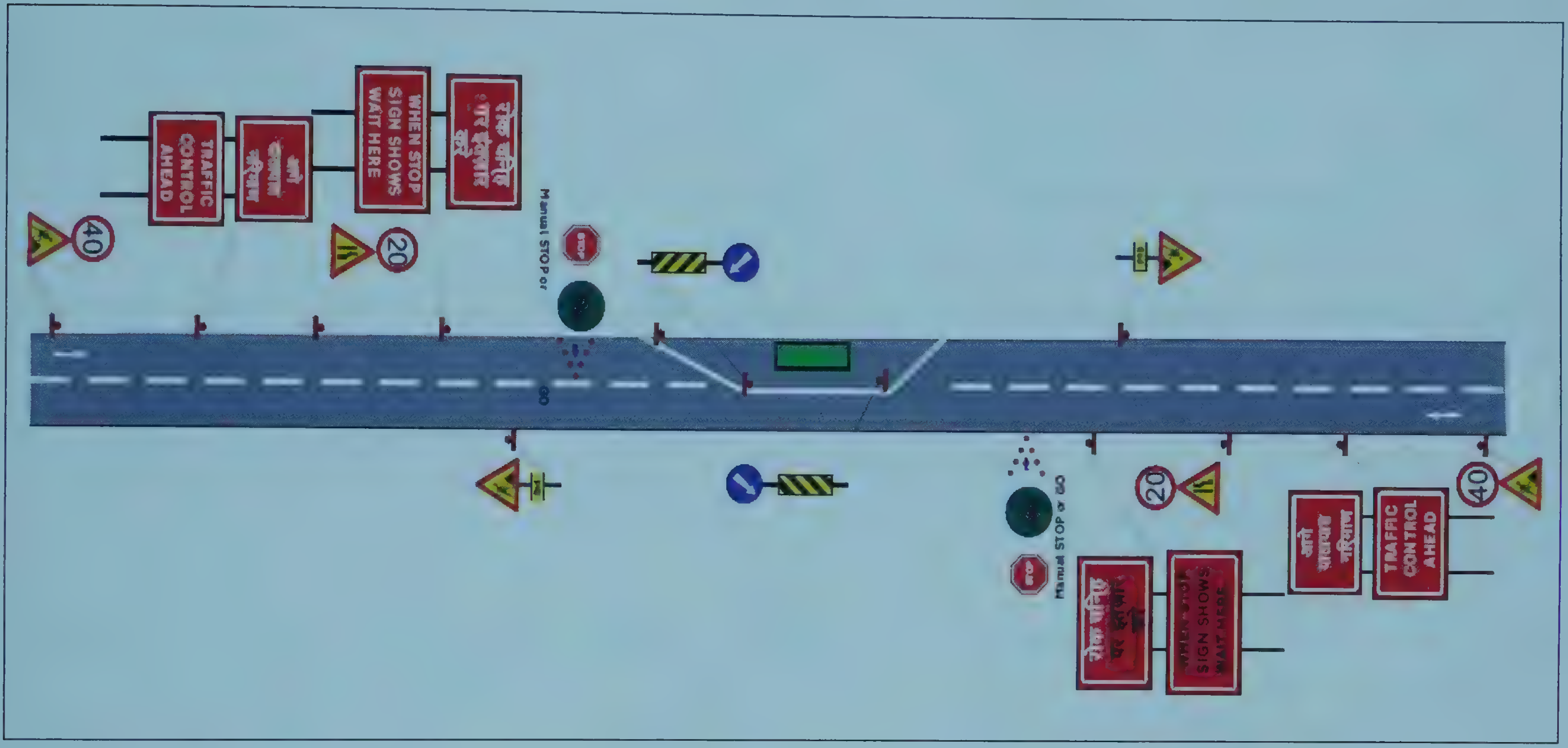


Fig. 8.2 Arrangements of Signs for Closure of One Lane

(a) In addition to the above a watchman shall be present at the barrier to control the traffic at all times. Police assistance may also be sought for in case of need. Necessary lighting arrangements may be made during night with flashing lights when required. The barricade shall be lighted with red warning lamps at night which shall stay lit from sun set to sun rise. In addition, alternate black and white diagonal strips shall be marked on barricades for effective advance warning, preferably with reflectorized paint.

(b) Signs, lights, barriers and other traffic control devices shall be kept maintained in a satisfactory condition till such time the traffic is restored and allowed to follow its normal path.

8.8.4.3 *Working in the Centre Line of Carriageway*

On hill roads, work on centre line of single lane roads like marking shall, preferably be done in the nights or early mornings, when traffic is very low as diverting traffic to half-width may not be practicable in all cases. The procedure laid down below may be followed in two-lane roads and at locations in single lane roads where passing traffic on half-width is possible:-

"The traffic should use available half-width. Cautionary and warning signs shall be installed as given in preceding paras 8.8.1.6 as per sequence given therein."

8.8.4.4 *Diversions*

In the interest of safety and convenience of traffic, appropriate measures must be taken whenever traffic on any section of a highway is to be diverted to another route, or made to sever from its normal path into another. Basic principles to be kept in mind are:

- i. that the traffic must be guided properly where it is required to follow an alternate facility,
- ii. given a clear warning of any hazards that may be present ahead.

  The typical situations arising in above are:-

  - a) Arrangement when traffic is suspended on a section of the road closed due to breach or damage.
  - b) Arrangement when traffic in part of carriageway is blocked due to landslides or repair/reconstruction of cross-drainage works etc. when traffic is allowed one way on part width or through a local diversion.

The above are dealt with in detail in **Chapter 11 "Traffic Management".**

8.8.5 *Symptoms, Causes and Treatment of Surface Defects*

8.8.5.1 The types of defects in bituminous surfacing are grouped under four categories as under:

- a) Surface Defects

  These include fatty surfaces, smooth surfaces, streaking and hungry surfaces. These are associated with the surfacing layers and may be due to excessive or deficient quantities of bitumen in these layers.

- b) Cracks

  Cracks can be broadly classified as hair-line cracks, alligator cracks, longitudinal cracks, edge cracks, shrinkage cracks and reflection cracks. A common defect in bituminous surface is the formation of cracks. The crack pattern can, in many cases, indicate the cause of the defect. As soon as cracks are observed, it is necessary to study the pattern in detail so as to arrive at the cause. Immediate remedial action should be taken there after because of the danger of ingress of water through the cracks and of the formation of pot holes and raveling. Cracks can hardly be observed from moving vehicles and inspection on foot is always essential.

- c) Deformation

  Deformation defects are slippage, rutting, corrugations, shallow depressions, settlements, and upheavals. Any change in the shape of the pavement from its original shape is a deformation. It may be associated with slippage, rutting, etc. The treatment measures aim at the removal of the cause, and bringing it to original level by fill material or by removing the entire affected part and replacing it with new material.

- d) Disintegration

  Disintegration covers defects like stripping, loss of aggregates, raveling, formation of potholes and edge breaking. These are some defects, which if not rectified immediately result in the disintegration of the pavement into small loose fragments and necessitate complete rebuilding of the pavement.

8.8.5.2 The details of various types of defects and their treatment are given in **Table 8.4** and broad specifications for sealing and patching materials in **Table 8.5**

Table 8.4 Symptoms, Causes and Treatment of Defects in Bituminous Surfacing

Sl. No.	Type of Distress	Symptoms	Probable Causes	Possible Type of Treatment
A. Surface Defects				
1.	Fatty surface	Accumulation of binder on the surface	Excessive binder in premix, spray or tack coat, loss of cover aggregates; excessively heavy axle loads	Sand blinding, open graded premix, liquid seal coat; burning of excess binder; removal of affected area
2.	Smooth surface	Slippery	Polishing of aggregates under traffic or excessive binder	Resurfacing with premix carpet.
3.	Streaking	Presence of alternate lean and heavy lines of bitumen	Non-uniform application of bitumen or at a low temperature	Application of a new surface
4.	Hungry surface	Loss of aggregates or presence of fine cracks	Use of less bitumen or absorptive aggregates.	Slurry seal or fog seal
B. Cracks				
1.	Hair line crack	Short and fine cracks at close intervals on the surface	Insufficient bitumen, excessive filler or improper compaction	The treatment will depend on whether pavement is structurally sound or unsound. Where the pavement is structurally sound, the crack should be filled with a low viscosity binder or a slurry seal or fog seal depending on the width of cracks. Unsound cracked pavements will need strengthening or rehabilitation treatment.
2.	Alligator crack	Inter-connected cracks forming a series of small blocks	Weak pavement, unstable conditions of sub-grade or lower layers, excessive overloads or brittleness of binder	----do----

3.	Longitudinal crack	Cracks in a straight line along the road	Poor drainage, shoulder settlement, weak joint between adjoining pavement layers or differential frost heave.	----do----
4.	Edge Crack	Crack near and parallel to pavement edge	Lack of support from shoulder, poor drainage, frost heave, or inadequate pavement width	----do----
5.	Shrinkage Crack	Cracks in transverse directions or inter-connected cracks forming a series of large blocks	Shrinkage of bituminous layer with age	----do----
6.	Reflection Crack	Sympathetic cracks over joints and cracks in the pavement underneath	Due to joints and cracks in the pavement underneath	----do----
C. Deformation				
1.	Slippage	Formation of crescent shaped cracks pointing in the direction of the thrust of wheels	Unusual thrust of wheels in a direction, lack or failure of bond between surface and lower pavement courses	Removal of the surface layer in the affected area and replacement with fresh material
2.	Rutting	Longitudinal depression in the wheel tracks	Heavy channelized traffic, inadequate compaction of pavement layers, poor stability of pavement material, or heavy bullock cart traffic	Filling the depressions with premix material
3.	Corrugations	Formation of regular undulations	Lack of stability in the mix, oscillations set up by vehicle springs, faulty laying of surface course	Scarification and relaying of surfacing, or cutting of high spots and filling low spots
4.	Shoving	Localised bulging of pavement surface along with crescent shaped cracks	Unstable mix, lack of bond between layers, or heavy start stop type movements and those involving negotiation of curves and gradients	Removing the material upto firm base and relaying a stable mix

5.	Shallow depression	Localised shallow depressions	Presence of inadequately compacted pockets	Filling with premix materials
6.	Settlement & upheaval	Large deformation of pavement	Poor compaction of fills, poor drainage, inadequate pavement, or frost heave	Where fill is weak, the defective fill should be excavated and redone. Where inadequate pavement is the cause, the pavement should be strengthened
D. Disintegration				
1.	Stripping	Separation of bitumen from aggregate in the presence of moisture	Use of hydrophilic aggregate, inadequate mix composition, continuous contact with water, poor bond between aggregate and bitumen at the time of construction, poor compaction etc.	Spreading and compacting heated sand over the affected area in the case of surface dressing, replacement with fresh bituminous mix with added anti-stripping agent in other cases.
2.	Loss of aggregate	Rough surface with loss of aggregate in some portions	Ageing and hardening of binder, stripping, poor bond between binder and aggregate, insufficient binder, brittleness of binder etc.	Application of liquid seal, fog seal or slurry seal depending on the extent of damage.
3.	Ravelling	Failure of binder to hold the aggregate shown up by pock marks or eroded areas on the surface	Poor compaction, poor bond between binder and aggregate, insufficient binder, brittleness of binder etc.	Application of cut-back covered with coarse sand, or slurry seal, or premix renewal coat
4.	Pothole	Appearance of bowl shaped holes, usually after rain	Ingress of water into pavement, lack of bond between the surfacing and base/sub-base layer, insufficient bitumen content etc.	Filling potholes with premix material or penetration patching
5.	Edge Breaking	Irregular breakage of pavement edges	Water infiltration, poor lateral support from shoulders, inadequate strength of pavement edges etc	Cutting the affected area to regular sections and rebuilding with simultaneous attention paid to the construction of shoulders.

Table 8.5 Broad Specifications for Sealing and Patching Materials for Repairing Defects *(Refer IRC:82)*

Sl. No.	Treatment	Binder	Aggregate	Specification in brief
1. Seal				
a)	Liquid seal	Penetration grade, cut-back or emulsion Rapid Setting	6.3 mm	Spray binder uniformly at 9.8 kg/10 sq.m. spread aggregate over it at 0.09 cu.m/10 sq.m and roll
b)	Fog seal	Slow setting emulsion diluted with equal amount of water	-	Spray binder at 0.5 -1 litre/sq.m. Allow traffic after seal sets. If considered necessary by the Engineer, apply tack coat with diluted emulsion at 2.5-3.5 kg/10 sq.m.
c)	Slurry seal	Slow setting emulsion	Well graded material between 4.75 mm and 75 micron	Apply slurry mix consisting of 18-20% emulsion and 10-12% water by weight of aggregate at the rate coverage of 200 sq.m. per tonne giving a thickness of 2 to 5 mm. No rolling is required.
2. Patching				
a)	Sand premix	Penetration grade, or cut-back (Rapid or Medium curing)	Fine grit 1.7 mm to 180 micron	Apply tack coat at 7.5 kg per 10 sq.m. Spread mix consisting of 0.06 cu.m. of grit and 6.8 kg of binder per 10 sq.m. and roll.
b)	Open graded premix	Paving grade, RC or MC cut-back, Medium setting emulsion	12.5 mm and 10 mm size aggregate	Apply tack coat, prepare the mix as per IRC:14 spread and roll. Where cut-back is the binder, the premix should be prepared at least 3 days in advance of use. The final surface should be provided with seal coat.
c)	Dense-graded premix	Paving grade bitumen	Well-graded as per IRC:29	Apply tack coat prepare and spread the mix as per IRC:29 and compact
d)	Penetration patching	Penetration grade, RC or MC cut-back	Coarse and key aggregate as per IRC:20	Apply tack coat, spread coarse aggregate and dry roll; apply binder and key aggregate and roll as per IRC:20. For patching 15-75 mm thickness, use BUSG as per IRC:47.

Notes :

i. *The area to be treated should be thoroughly cleaned prior to application of the remedial treatment.*

ii. *If it is a pothole the edges of the hole should be square and cut to solid material with vertical edges.*

iii. *The treatment area should be dry unless the binder is an emulsion.*

iv. *The areas where fresh material is applied should be finished in line with the adjoining pavement.*

v. *For more details on the construction procedure, reference should be made to IRC:82.*

8.8.6. *Technology for Maintenance*

8.8.6.1 The spectrum of technologies available for maintenance of hill roads ranges from labour based to machine/equipment based and combination of labour and machines (intermediate) although the relative proportions can differ substantially. While the socio-econimic conditions in India indicate labour based maintenance to provide employment to a large number of people, it may be necessary to use equipment to achieve specified quality and in the interest of speedy achievement of the end product.

8.8.6.2 Even the labour based methods have to use certain items of obligatory equipment on maintenance (except probably on light vehicle roads, Bridle road/paths) such as compaction equipment (Rollers), vehicles for transportation, earthmoving equipment for landslide clearance, compressors and drills for blasting or quarry operation, bitumen heaters and distributors, etc. For snow clearance operations, bulldozers and special snow clearance equipment will also be needed. Machinery becomes an obligatory requirement as it will not be possible to get all the maintenance activities on a hill road executed purely by manual labour considering magnitude of the task, necessity to clear road blocks and slides without delay and for quality outputs. Hence policy should be made out grading the roads for purposes of maintenance as 'Labour Based,' "Machine Based" and combination to a pre-determined proportion and scales worked out as given under para 8.5.4 'Scale of Maintenance' paras 8.5.4.1 to 8.5.4.2 ante. The machinery required for each road depending on its priority, behaviour and climatic conditions should be decided and allotted.

8.8.6.3 Use of animals, where available, are also very useful and cost effective in maintenance activities. It may be possible to use agricultural equipment like tractors, trailers, etc. for grading, haulage, digging, etc.

8.8.7 Maintenance of Drains, Cross-Drainage Works, Shoulders and Slopes

8.8.7.1 Maintenance of Drainage

The objective is to ensure that drainage elements remain free of obstruction and retain their intended cross sections and grades. They must function properly so that surface and sub-surface water can drain freely and quickly away from the road or under the road. The maintenance activities on the drainage system are given below:

a) Side drains, catch water drains, sub-soil drains (dealt as Drains)

  I. Routine Activities

    - Reshape/regrade/deepen
    - Clearing and Cleaning
    - Erosion Repair

- II. Periodical Activities
  - Provision of lateral ditches (turn out)

b) Culverts

- I. Routine Activities
  - Clearing and cleaning including catchpits
  - Repair to cracks
  - Erosion repair
  - Repair to protection works
- II. Periodical Activities
  - Repair of Invert
  - Repair of walls, aprons etc.
  - Repair of Chute and Guide walls

c) Causeways

- I. Routine Activities
  - Minor surface repair
  - Replacing guide posts
  - Replacing flood gauges
  - Repairing protection works
- II. Periodical Activities
  - Repairs of floor
  - Repairs of head walls
  - Repairs of apron

8.8.7.1.1 Inspection

Inspection of drainage system is an year round task. Structure must be examined in dry season when little or no water is flowing so that structural damage cracks, settlement, erosion, etc., can be seen better, identified and repaired well as, waterway cleared of debris. The functioning of drainage system during the rainy season should also be inspected. Special emphasis must be given to inspection of drainage works during thaw period at end of winter in snow bound area to identify crucial places and their clearance on priority to avoid damage to roads. If surface and ground water drains freely as intended, the system can be deemed satisfactory, otherwise there is something wrong and needs to be repaired.

For Example:

- If a culvert outlet discharge is small when the inlet is at full head or submerged, the culvert is not functioning or is damaged/cracked in flooring/abutments

- Where the carriageway does not have an adequate camber or cross fall. the surface water will pond on the surface and accelerate the formation of ruts, potholes and unintended ditches.
- Where drains have little or no scope or inadequate turn outs, silting will occur and cause ponding of water and weakening of pavement.

8.8.7.1.2 Inspection check list

These are given below:

a) Drains

- Drain cross section destroyed
- Ponding in drain
- Erosion

b) Causeways

- Potholes in paved surface
- Cracks In paved surface
- Guide posts missing
- Flood gauge missing/tilted
- Damage to curtain wall/appron

c) Culverts

- Silting, sanding, blockage by debris or frozen water
- Erosion at Inlet and outlet
- Settlement cracks
- Damage to flooring and parapets
- Damage to apron, chutes and guide walls

8.8.7.1.3 Defects, causes, effects and remedies

These are listed below:

a) Drains

i. Defect - ponding

Cause and effect - Cross section too small or grade improper, the shoulder material becomes soft and can easily erode. The pavement can also be flooded and thus weakened.

Activity - Enlarge cross section or regrade drain

ii. Defect silting

Cause and Effect - Invert slope is too flat, the water cannot flow at sufficient velocity. If neglected the drain will get blocked.

Activity - Deepen drains (desilting) giving proper grades and/or provide lateral drains (turn outs)

iii. Defect - Uneven drain invert varying cross section

Cause and Effect - Blockade by debris, and vegetation; if neglected cross section is reduced and water cannot flow as intended.

Activity - Cleaning, Clearing, repairing.

iv. Defect - invert and sides of drains are eroded

Cause and Effects - Invert slope is too steep. If neglected, water flows at too high a velocity and starts carrying away the soil. The drain becomes deeper (ravine). The sides then cave in, the shoulder or even part of carriageway can get washed away.

Activity - Reinforce drain slopes and invert regarding/realigning drains. Provision of drain checks.

b) Causeways

The surface of causeways is endangered by washouts and slush movement caused by water current. Routine maintenance in this case can only by regarded as temporary measure. The activities include masonry repair, placing of stone crates; and erosion protection of causeway openings.

i. Defect - cracks in paved surface

Cause and Effect - Settlement of slab. If neglected, the cracks in concrete slab spread and widen especially during the following flood season.

Activity - Minor surface repair (sealing cracks)

ii. Defect - guide posts/flood gauges are missing or damaged

Cause and Effect - Accident, vandalism, flood damage. If neglected, when the pavement becomes submerged during flood and the edge of pavement cannot be seen, vehicles can accidentally drive into deep water.

Activity - Replacing guide posts.

c) Culverts

i. Defects - silting, sanding, blockage by debris

Cause and Effect - Invert slope too flat.

- Culvert constructed too low and hence material from stream gets deposited on the culvert bed.

- Vegetation and flooding debris carried by water have got lodged in the culvert. If neglected, the intended waterway opening will be so reduced that flood water cannot flow. It will back up or pond on the upstream side of culvert and may eventually overflow the road formation. The road is in danger of being washed away.

Activity - Cleaning and clearing. If flooding debris is a problem, the provision of debris rack should be considered.

ii. Defect - Erosion of stream bed at culvert inlet and outlet

Cause and Effect - The culvert invert has been constructed on too steep a grade so that water flows too fast and/or the stream water penetrates below the culvert bed.

- If neglected, the stream bed is eroded and a pool or ravine developes. The culvert downstream head wall and wing walls and even a section of the culvert and road formation can collapse into the pool or ravine.

Activity - Erosion repair and provision of toe wall, pitching of stream bed, pitching of chutes, reconstruction of guides walls.

iii. Defect - settlement cracks

Cause and Effect - Settlement of soil below culvert

- Minor damage - if the settlement is minor, only light cracking will result in head walls, wing walls and main structure. This will hardly affect the functioning of the structure.

- Major damage - if the settlement is average, it will cause large relative movement of culvert body so that formation soil will enter through the cracks and block the culvert or that the culvert may collapse.

Activity - Crack repair for minor damage. Sealing cracks with clay/ bituminous mulch to extend life of culvert and reconstruct in the event of collapse.

8.8.7.2 Maintenance of Slopes

A hill road is formed by cutting slopes or forming slopes and stability of the road is dependent on slope stability/protection measure itself. It is therefore essential that the slopes are protected and maintained to designed standards/specifications and corrective action taken, whenever the slope is disturbed. This may require refurbishing the slope stabilization/protection measures already in place or taking up stabilization/protection measures.

8.8.7.3 *Maintenance of Shoulders (Berms)*

(a) Shoulders provide lateral support to the pavement. They are used for parking vehicles in case of single lane roads, provide room for passing vehicles where carriageway width is insufficient and also comes in handy for the parking of disabled vehicles. These at times serve as a track for slow moving vehicles. Properly maintained shoulders also help the drainage of surface water quickly to the side drains. Improper maintenance of shoulders will cause drainage water to flow along the edge of the pavement resulting in caving and thereby penetration of moisture to the subgrade.

(b) In order to perform the functions stated above satisfactorily it is necessary that the surface of the shoulders are hard enough to resist the abrasive action of vehicles and the disrupting influences of the elements of nature.

(c) The shoulder surface should always slope uniformly (as per standards) from the edge of the pavement so that any water falling on the road surface or shoulders is speedily drained off. Paved or hard shoulder reduces the problem considerably and shall be preferred in high vegetation areas to reduce maintenance efforts and affording better visibility for traffic appurtenances thereby making roads safer.

(d) The work of maintenance of earth shoulders consists of periodically replacing earth or moorum carried away from the shoulders, to remove ruts and restore the slope to the designed level. This work is generally heavy during and after the rains.

8.8.8 *Maintenance of Structures*

(a) Structures like retaining/breast walls, toe/check walls, chutes and guides, parapets, rallings, etc. on the road have to be maintained always in a good state so that they perform their designed role. To achieve this, regular inspection/ checks to identify any damages/inadequacies should be carried out as brought out earlier in this chapter and repairs promptly carried out.

(b) All repairs have to be completed before rainy season and any damages in rains temporarily repaired immediately must be permanently restored as soon after the rainy season, as possible.

(c) All bridges must be maintained and periodical repairs and protection works carried out as per normal laid down practice.

8.8.9. *Maintenance of Road Furniture*

(a) Traffic signs: Traffic signs are the principal means of conveying information about the road to drivers and as the road network becomes more extensive the number of traffic signs increases. As traffic flow increases, an increasing effort on their maintenance is needed. Signs which are clean and in good condition can be easily seen and understood and inspire confidence that their message is accurate and reliable. Damaged or missing signs shall, for the same reasons, be replaced promptly, and temporary signs shall be removed upon completion of the maintenance works to which they are related. The provision and care of signs is very cheap and cost effective. Signs should be inspected, cleaned and repaired if necessary at least twice a year. It is worth keeping records of traffic signs. They should be included in an inventory and transferred to a signs register in which details of inspections, repairs and replacements are recorded. It is useful if their location is also recorded in strip map.

(b) Road Marking: - Road markings are laid on the pavement either temporary or for long term purposes. The life of the road markings is limited to the duration of the working zone. In the case of long-term purpose road markings, it is appropriate to consider the reasons of safety to have a functional life that lasts for at least two years. The road authority must demand for a warranty period for the pavement marking. During the warranty period, all the performance parameters must remain higher than the minimum threshold level. Performance parameters shall be checked every year on a random section of the network conforming to the procedure presented in IRC:35 for the i) Day time visibility, ii) Nighttime dry retro reflection, iii) Night time wet retro reflection.

(c) Road Stud and Solar Stud: - Numbers and Functionality as per specifications of the installed road studs and solar studs to be checked by counting the numbers physically present at the site and checking luminance value during the warranty period.

(d) Railings: Guard-rails and parapet rails are provided to protect road users; to prevent vehicles from running over high embankments or valley side and parapet rails on bridges to safeguard pedestrians and vehicles. Railings shall be repaired promptly, if damaged and kept clean and repainted regularly so as to maintain their visibility.

(e) Kilometre stones: These provide both drivers and the maintenance organisation with the basic reference for the location of any point on the road. Kilometre stones shall be kept clean and repainted regularly and vegetation around these shall be cleared so that they can easily be read from a moving vehicle.

(f) Marker stones: Each Bridge Culvert and other structures shall be serially numbered within the Kilometre in which it is located thus: 80/2 is the second culvert or bridge in Km 80. These numbers shall be marked on parapets/ structures or Separate marker stone placed firmly near the structure and used as references in the culvert and bridge registers. The painting of markers shall be maintained properly for easy identification.

(g) Delineators: These are usually provided only on high bank or on bends. It shall be kept clean regularly. The design of Delineator shall confirm as per IRC:79. Vegetation around the delineators shall be cleared so that these can be easily seen from a distance.

8.8.10 *Repairs to Damages of Pavement*

Repairs to damages of pavement like potholes and depression form another important maintenance task. Such repairs shall be done to regular shape and should match the existing surface to correct level and grade. Paras 8.7 "Maintenance Criteria" and 8.8.5 "Symptoms, causes and treatment of surface defects" may be referred.

8.8.11 *Miscellaneous Repairs/Maintenance*

Vegetative growth from roadside berms and from hill slopes for a height of atleast 2 m above the road level shall be trimmed regularly.

8.8.12 *Special Problems and Techniques for Maintenance of Road in High Altitude and Snow Fall Areas:*

(a) The main problems in maintenance of roads in high altitude areas are of drainage caused by rapid melting of snow during spring, extreme cold climate during winter and consequent restrictions in working. Loss of efficiency of men and machines in the rarefied atmosphere is also a major problem.

(b) Drainage problems: There is scanty rainfall in most of the high altitude areas (except in certain high altitude areas of Eastern Himalayas where rainfall also is fairly high) and most of the precipitation consists of snow. The drainage problems are mostly due to thawing of snow and ice. Temperature rise during the day results in rapid melting of snow with the advent of spring.

(c) The streams in the region have heavy floods during spring. Large amount of debris and ice carried in such streams results in more drainage problems. Since the soil surface is invariably frozen at the end of winter, there is no absorption of moisture by the soil and the run off coefficient is sometimes as high as 100 per cent. Flash floods also sometimes occur in the streams due to breaking of glacier dams and cloud bursts. The major factors responsible for drainage problems in these regions include temperature, humidity, snowfall and consequent run-off, nature of soil and catchment area, etc.

(d) Problems of snowfall: The problems due to snow and avalanche on hill roads is dealt elaborately in **Chapter 6 "Snow Clearance and Avalanche Treatment".** But the important aspects related to maintenance of hill roads are reiterated here.

Heavy snowfall combined with severe cold climate causes numerous problems for the maintenance of roads at 'high altitudes. The problems faced are as under:

(i) Slow seepage: In stretches subjected to heavy snowfall melting of snow results in slow seepage into sub-soil and subgrade causing subsidence of subgrade over long lengths. Slow seepage from the accumulated snow above road formation also destabilises the hill slopes above the road formation resulting in landslides.

(ii) Snow avalanches: Often huge accumulation of snow comes down the slope at great speed and brings boulders and debris. Such avalanches along the re-entrants cause considerable damage to road formation, pavement and permanent structures, apart from the potential danger to traffic, life and property.

(iii) Drainage problems during snow clearance: During heavy snowfall large stretches of road are affected. For the quick opening of the road communication, normal practice is to clear minimum road width required for passing of vehicles for one way traffic, in the first instance. The restricted width of road acts as drain for melting snow and causes slow seepage of water in road crust and subgrade and often causer damages to road crust/settlement of subgrade.

(iv) Effect of Frost: Freezing of water behind the retaining wall causes cracks in the structure due to increases in volume of back fill. Formation of ice pockets in some stretches also causes heaving of subgrade and crust.

(v) Icing problems: Where a thin layer of snow has remained on pavement for some time, it becomes more dense and compact due to drop in temperature caused by cold wind blowing on the surface during winter month and also hardening effect of moving traffic. The top layer of snow on road is rapidly coated with an ice glaze, which is very hard, slippery and extremely dangerous for traffic due to the skidding effect of vehicles. This thin layer of ice poses great problems for removal as it is hard and adhere tenaciously to paved surface.

(vi) Restricted efficiency of men and machines: Efficiency of men and machinery decreases at high altitudes due to lack of oxygen, low atmospheric pressure and severe climatic conditions. Working hours are also restricted. Working season for constructing woks involving cement and bitumen is normally limited between middle of May to middle of November. The loss of efficiency of men and machines above 2100 m altitude are given in Table 7.1 under Chapter 7 “Road Construction Tools, Plants and Equipment”.

(e) Remedial measures: The remedial measures for above are given as under:

(i) Melting effects of snowfall

- Quick removal of snow from whole formation by using wheel dozers, motor graders and special rotary cutter type snow clearance machines.
- Clearing of roadside drains promptly.
- If restricted width of road has been opened due to compulsion of providing prompt road communication by clearing snow, then cross drains must be opened on either side of the road at intervals to guide melted snow water valley sides or roadside drains.

(ii) Effect of frost/icing

- Efficient drainage of water is to be ensured from back face of retaining/breast walls through weep holes etc. Surface water on road formation and drain should not be allowed to stand but drained out quickly so that the same does not seep through to the subgrade. Common salt/urea can be sprinkled on ice/frost on critical stretches to cause deicing and avoid skidding and slipping of vehicles.

(iii) Problems in maintenance of machinery: In high altitude areas, the work is mainly equipment oriented. The maintenance of equipment and machinery requires planning as various types of snow clearance machinery and vehicles are involved and repairs have to be carried out on an emergency basis. Temperature prevailing in most of the snow clearance detachment/locations can be much below subzero level. Proper precautions for men engaged on repairs/maintenance of the equipment have, therefore, to be ensured. Apart from providing the man with adequate snow clothing, the repair workshop shed should also be kept warm by use of heaters. Some of the preventive maintenance measures for the equipment are:

- Radiators are drained or wrapped up after working hours.
- Batteries are removed and kept in heated/covered rooms.
- Bulb zero diesel is used as primary oil.
- Close and proper check on appropriate lubricants is ensured.

(iv) Problems of providing the required spares: For equipment, plant and vehicles for snow clearance efforts also need close attention and advance planning for ensuring timely procurement and placement of spares at appropriate places. This is particularly so for snow clearance equipment which are of foreign make as procurement of spares for repairs of fuel injection pump assembly, hydraulic pump assembly, Impellers, outer blade, etc., involves long range advance planning, in view of the long lead time involved for materialization.

8.9 Organizing Maintenance and Operations in the Field

In the preceding paragraphs the aspects of maintenance from objective to execution has been dealt with. To ensure effective maintenance, it is essential that organization deployed on maintenance task under the engineer-in-charge of maintenance is armed with a systematic operational procedure and step-by-step methodology. Such a system should be evolved for each road or group of roads depending on the ground, terrain, topographic, climatic and traffic conditions and user requirements.

8.10 Monitoring

An efficient system of monitoring the maintenance task should be evolved so that the performance is studied for upgradation of technology in rendering better service to the road user and traffic.

8.11 Training in Maintenance Operation and Management

8.11.1 Training of all the personnel involved in maintenance is an integral part of the maintenance function. Such training, as may be required by the operating and maintenance personnel to achieve better performance, can be classified as below:

a) Training of engineering subordinates

b) Training of skilled manpower /Gangmen/Mate

8.11.2 *Training of engineering subordinates*

The engineering subordinates are expected to perform all the necessary management tasks even without formal management orientation or training. The supervisor learns about type maintenance work on precedent practice and a new supervisor/engineer handles the job in the same manner as the person before him. Techniques which may or may not have worked in the past are tried again. Supervisors/Engineers must be provided with the opportunity to attend maintenance management and operations training. This may be done wither at site by the renowned Training Institutes like Indian Academy of Highway Engineers (IAHE) or technical personals may be sent to these institutes. The areas to be covered during the training should be:

a) Identification of defects

b) Planning maintenance operations effectively

c) Crew scheduling and control to achieve higher productivity at low cost consistent with quality.

d) Problems of crew supervision-communicating and coordinating

e) Preparing road inventory

f) Management by objectives

g) Repair methods

8.11.3 *Training of Skilled Manpower/Gangmen/Mates*

Trained Technical manpower / Engineers may impart the training to maintenance gangmen / skilled manpower in two areas is very essential as under:

I. Safety aspects

II. Repair methods

(I) The training in safety aspects will include:

   a) Training of flag-men

   b) Use and lay out of temporary traffic signs for repair works

   c) Safety oriented handling and parking of machinery and equipment

   d) Safety in slide areas

   e) Safety in snow fall conditions

(II) The training in repair methods will include:

   a) Slide clearance

   b) Snow clearance

   c) Drain maintenance

   d) Proper patching methods

   e) Proper grading of shoulders

f) Maintenance of drainage structures

g) Crack sealing

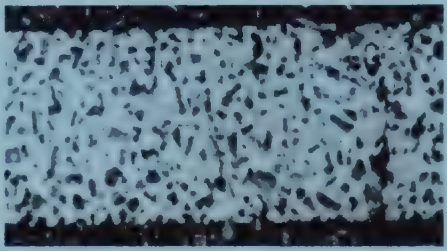
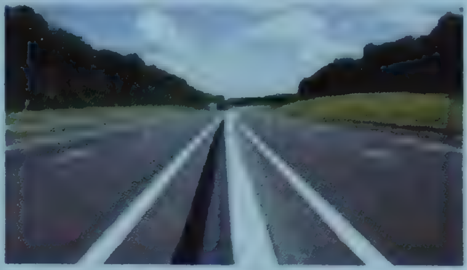
h) Painting and maintenance of the traffic signs and warnings

i) Equipment maintenance

8.12 Formats for Various Data

Ministry of Road Transport and Highways “Manual for Maintenance of Roads” may be referred for details of certain formats for recording field data, duties of subordinate staff, etc. engaged for maintenance.

Maintenance requirements for road signs, road marking and road furniture are given in this table below:

Asset Type	Performance Parameter	Level of Service (LOS)	Frequency of Measurement	Testing Method	Recommended Remedial measures	Time limit for Rectification
Pavement Marking	Wear	<70% of marking remaining 	Bi- Annually	Visual Assessment as per Annexure-F of IRC:35-2015	Re - painting	Cat-1 Defect -within 24 hours Cat-2 Defect within 2 months
	Day time Visibility	During expected life Service Time Cement Road - 130mcd/m2/1ux Bituminous Road - 100mcd/m2/11tx 	Monthly	As per Annexure-D of IRC:35-2015	Re - painting	Cat-1 Defect - within 24 hours Cat-2 Defect- within 2 months
	Night Time Visibility	Initial and Minimum Performance for Dry Retro reflectivity during night time: Values to be minimum 80% of the threshold level Design Speed | (RL) Retro Reflectivity (mcd/m2/1ux)	Bi-Annually	As per Annexure-E of IRC:35-2015	Re - painting	Cat-1 Defect- within 24 hours Cat-2 Defect - within 2 months

			Initial (7 days)	Minimum Threshold level (TL) & warranty period required up to 2 year			
		Up to 65	200	80			
		65 - 100	250	120			
		Above 100	350	150			
	Night Time Visibility-Wet Condition	Initial and Minimum Performance for Night Visibility under wet condition (Retro reflectivity): Initial 7 days Retro reflectivity: 100 mcd/m2/lux Minimum Threshold Level: 50 mcd/m2/lux Wet retro-reflectivity should not be than 70% of minimum threshold level		Bi-Annually	As per Annexure-E of IRC:35-2015	Re - painting	Cat-1 Defect- within 24 hours Cat-2 Defect - within 2 months
Road Signs	Shape and Position	Shape and Position as per IRC:67 Signboard should be clearly visible for the design speed of the section.		Daily	Visual with video/image backup	Improvement of shape, in case if shape is damaged. Relocation as per requirement	48 hours in case of Mandatory Signs, Cautionary and Informatory Signs (Single and Dual post signs) 15 Days in case of Gantry/Cantilever Sign boards
	Retro reflectivity	As per specifications in IRC:67 		Bi-Annually	Testing of Each signboard using Retro Reflectivity Measuring Device. In accordance with ASTM D 4956.	Change of sign boards	48 hours in case of Mandatory Signs, Cautionary and Informatory Signs (Single and Dual post signs) 1 Month in case of Gantry/Cantilever Sign boards

Kerb	Kerb Height	As per IRC:86 depending upon type of Kerb	Bi-Annually	Use of distance measuring tape	Raising Kerb Height	Within 1 Month
	Kerb Painting	Functionality: Functioning of Kerb painting as intended	Daily	Visual with video/image backup	Kerb Repainting	Within 7-days
Other Road Furniture	Reflective Pavement Markers (Road Studs)	Numbers and Functionality as per specifications as per IRC:SP:84, IRC:SP:87, IRC SP:73 and IRC:35	Daily	Counting	New Installation	Within 2 months
	Solar RPM	Numbers and Functionality as per specifications as per IRC:SP:84, IRC:SP:87, IRC:SP:73 and IRC:35	Daily	Counting	New Installation	Within 2 months
	Median Marker	Numbers and Functionality as per specifications as per IRC:79	Daily	Counting	New Installation	Within 2 months
	Object Marker-AFP	Numbers and Functionality as per specifications as per IRC:79	Daily	Counting	New Installation	Within 15 days
	Pedestrian Guardrail	Functionality: Functioning of guardrail as intended	Daily	Visual with video/image backup	Rectification	Within 15 days
	Traffic Safety Barriers	Functionality: Functioning of Safety Barriers as intended	Daily	Visual with video/image backup	Rectification	Within 7 days
	Attenuators	Functionality: Functioning of Attenuators as intended	Daily	Visual with video/image backup	Rectification	Within 7 days
	Guard Posts and Delineators	Functionality: Functioning of Guard Posts and Delineators as intended	Daily	Visual with video/image backup	Rectification	Within 15 days
	Overhead Sign Structure	Overhead sign structure shall be structurally adequate	Daily	Visual with video/image backup	Rectification	Within 15 days
	Traffic Blinkers	Functionality- functioning of Traffic Blinkers as intended	Daily	Visual with video/image backup	Rectification	Within 7 days

9. ROADSIDE AMENITIES

9.1 General

The provision of roadside amenities in Hill roads contribute to a large extent in ensuring safety besides making the journey convenient and pleasant. The type of amenity, its location and its frequency depend on many factors which include classification of highway, traffic volume, type of vehicles, steepness of grades, road geometrics, terrain and environment. Main amenities which need consideration are scenic overlook, fuel stations, servicing areas, recovery posts, water points, lay-byes, walkways in tunnels and on bridges, rest areas, restaurants, shelters against rain/snow at bus stops, emergency telephones, traffic aid posts, tourist information centers, guide maps and facilities at check posts/border posts. In view of the safety aspects involved, it is of paramount importance that the need for amenities and their provision should be incorporated into the regular planning, design, construction and maintenance/improvement practices followed in hill roads. The requirement of each of the amenities is discussed in subsequent paras.

9.2 Scenic Overlooks

It is quite natural for a traveler to be attracted by a sight of natural beauty or some other point of interest. This results in distraction and haphazard parking at such location causing bottlenecks and accidents. It is, therefore, advisable to provide a separate lay bye at such locations for parking and combine these with rest areas wherever possible. Sign posts should also be posted as per IRC:67 to inform the user of its location. The design of lay bye should be adequate to cater to the volume of traffic expected to stop at the location.

9.3 Fuel Stations, Service Stations and Watering Points

Driving on hill roads is strenuous both for the driver and the vehicle. Invariably the engines generate more heat in continuous climbs and low gears and drivers often stop to feed water at natural water courses. At such locations extra widening or separate lay bye should be provided. Besides this, oil consumption increases and wear on brakes etc. also gets pronounced. As such, arrangements for refueling, oil check, water and air pressure check and normal repair and servicing become essential facilities required for vehicles. The fuel stations may be provided as a part of the rest area complex or standalone along the highways. Rest areas should have various amenities for users, e.g. places for parking, toilets, restaurants, rest rooms, kiosks for selling sundry items, bathing facilities, repair facilities, crèche etc. These aspects should be incorporated while planning for improvement and up-gradation of Hill road sections and/or planning for new fuel stations along the Hill roads. The IRC:12 provides guidance on fuel filling stations and service stations. These should be adopted with necessary changes to suit hill roads.

9.4 Rest Areas/Rest Houses/Truck Lay Byes/Toilet Facilities

9.4.1 Research in road safety has shown that a major cause of fatal accident is fatigue and/or driver falling asleep at the wheel. To avoid such occurrences, it is desirable to provide rest areas at every 3 hours driving time distance. The facilities to be provided would depend on the volume of traffic. On low density traffic routes, where higher type of development is not feasible, parking spaces, toilets and minimum shelter with table/benches can be provided. Since, in hilly areas, not much land is available, these areas could be combined with scenic overlooks. The

Ideal roadside rest areas should have fully equipped shelter, cafeteria, restaurant, parking for car, buses and trucks, drinking water facilities, dormitory, rest rooms, shops for travel needs, garage, fuel station, first aid shall be available. There shall be provision of waste receptacles and sufficient area lighting. Self-draining soakage pit system of disposal which require minimum attention is desirable. Special care exercised to exclude alcohol and other drugs which compromise driving ability of driver and safety. The whole area shall be elaborately landscaped to provide a pleasing environment. Typical Layout of Truck laybye are shown in **Fig. 9.1.**

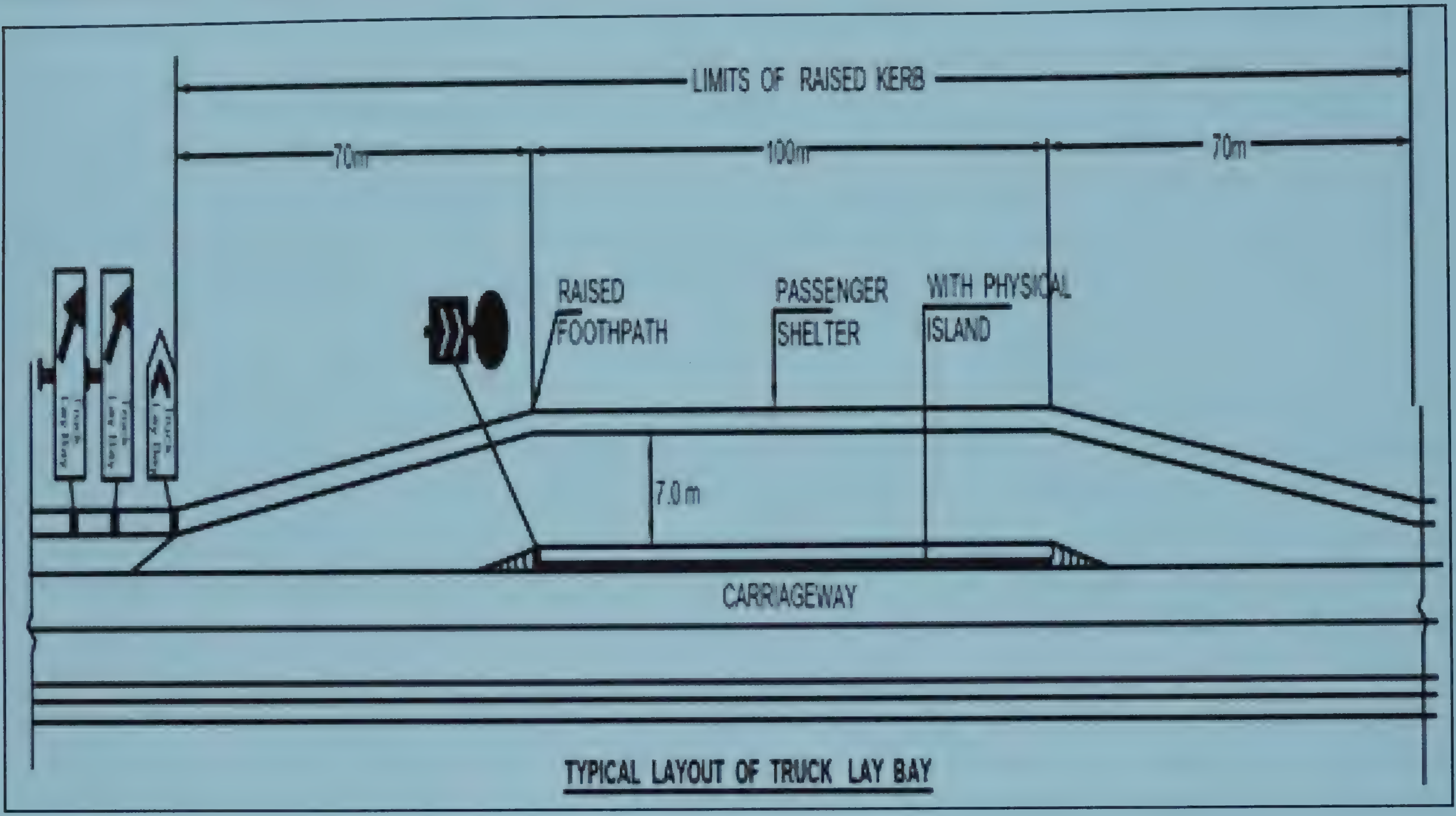


Fig. 9.1 Typical Layout of Truck Laybys (dimensions in mm)

9.4.2 In providing such facilities, great care should be taken to, maintain cleanliness and tackle the problem of disposal of rubbish litter etc. and in provision of sanitary facilities. The main requirement at such places is that there should not be any contamination of ground water, surface water or surface soil and that the excreta should not be accessible to flies or animals and the area should remain free from odours or unsightly conditions. At the same time, the disposal method should be simple and inexpensive in construction and operation. **Figs. 9.2** and **9.3** show typical plans for such areas. These would need modification according to site slopes and conditions.

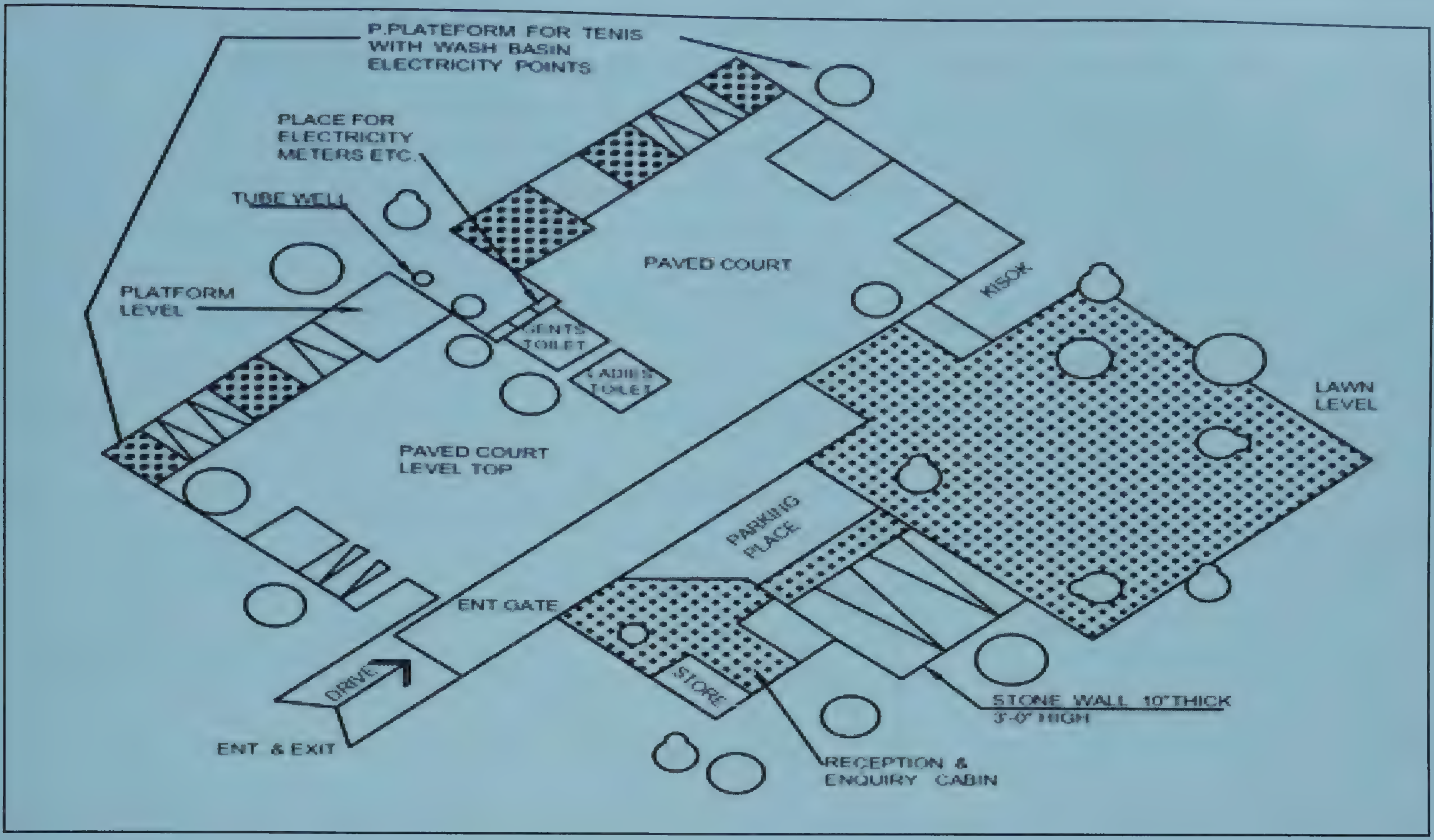

P.PLATEFORM FOR TENIS
WITH WASH BASIN
ELECTRICITY POINTS
PLACE FOR
ELECTRICITY
METERS ETC.
TUBE WELL
PLATFORM
LEVEL
PAVED COURT
GENTS
TOILET
LADIES
TOILET
KISOK
LAWN
LEVEL
PAVED COURT
LEVEL TOP
PARKING
PLACE
ENT GATE
DRIVE
ENT & EXIT
STORE
STONE WALL 10"THICK
3'-0" HIGH
RECEPTION &
ENQUIRY CABIN

Fig. 9.2 Highway Development Plan
(Typical Tourist Camping Ground Lay-Out Plan)

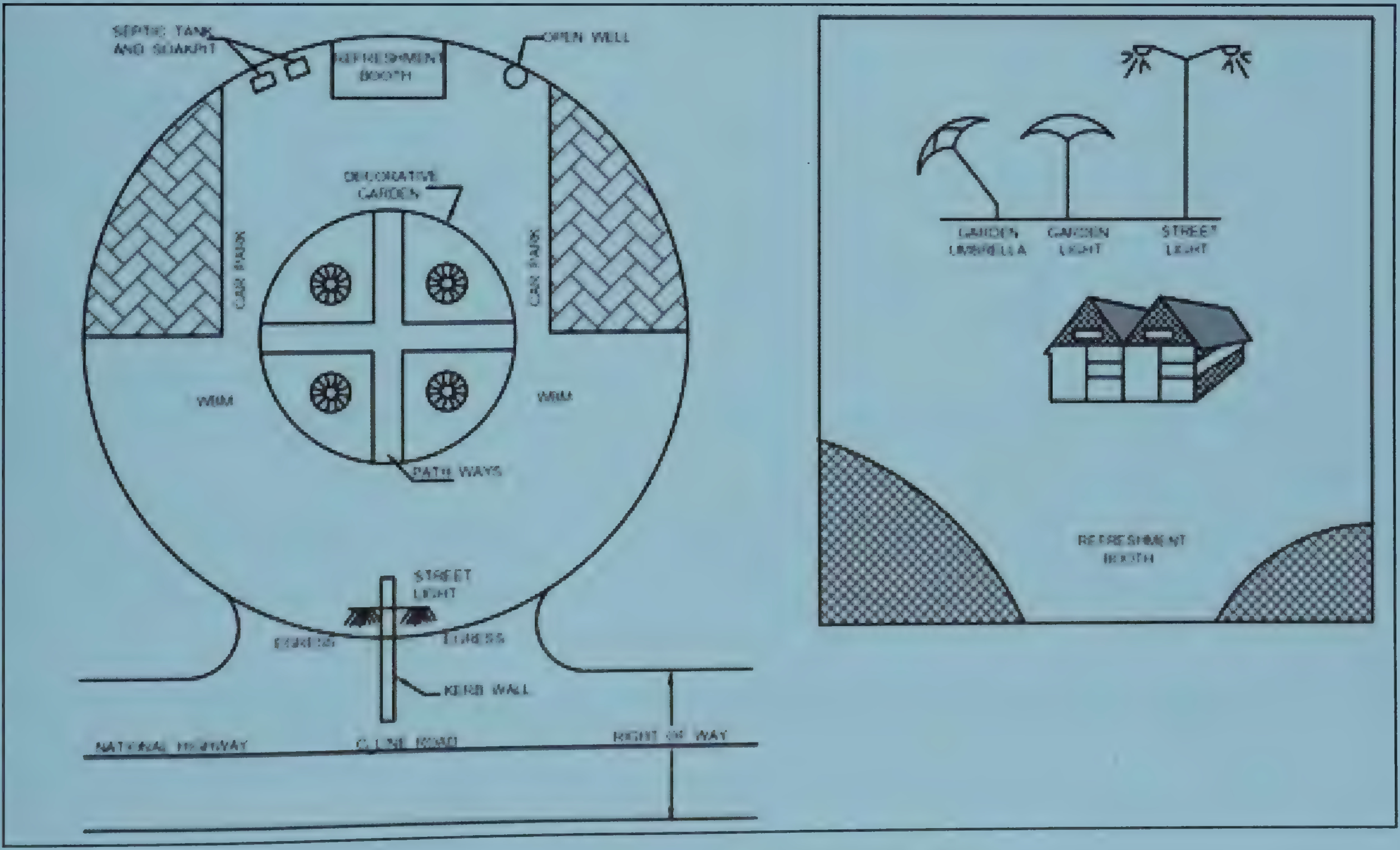

SEPTIC TANK
AND SOAKPIT
REFRESHMENT
BOOTH
OPEN WELL
DECORATIVE
GARDEN
CAR PARK
CAR PARK
WIM
WIM
PATH WAYS
STREET
LIGHT
EGRESS
EGRESS
KERB WALL
NATIONAL HIGHWAY
C LINE ROAD
RIGHT OF WAY
GARDEN
UMBRELLA
GARDEN
LIGHT
STREET
LIGHT
REFRESHMENT
BOOTH

Fig. 9.3 Highway Development Plan
(Amenities – Typical Wayside – Restaurant)

9.4.3 In hilly areas, there are several locations, where buses make short stop-overs for alighting/getting down of passengers. These should be provided with a lay-bye with a suitable shed for waiting passengers. A typical design is shown in **Fig. 9.4**. The bus stop should normally be located where the road is straight on both sides, the gradient is level or as flat as possible and the visibility is reasonable (not less than 50 m). It is advisable to choose locations where it is possible to widen the roadway economically for accommodating lay-byes, passenger shelter etc. The hill slopes should be properly dressed and suitably protected to avoid slips. Water should be drained away from the lay-bye area. Suitable signs should also be provided at and in advance of such locations.

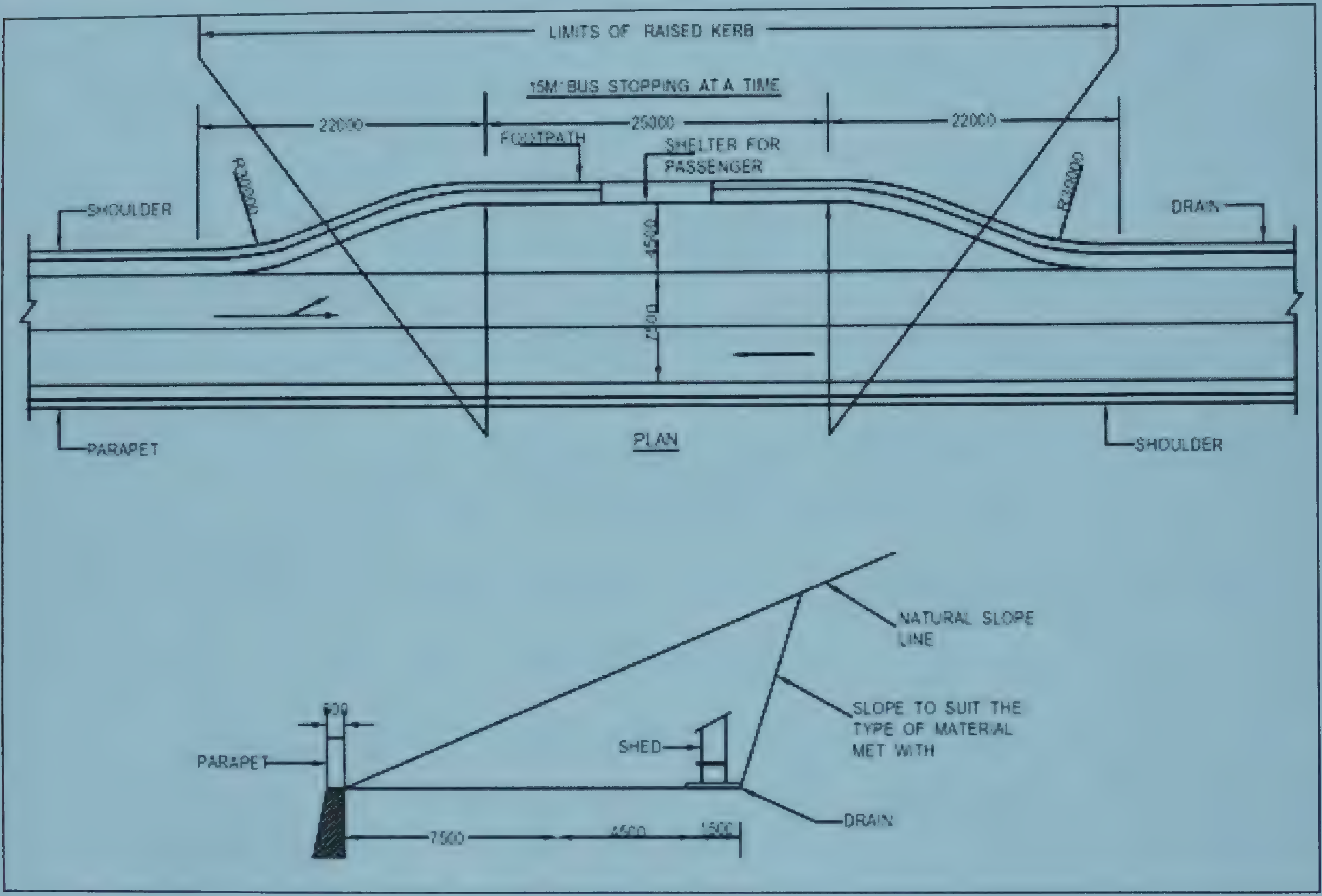

LIMITS OF RAISED KERB
15M BUS STOPPING AT A TIME
22000
25000
22000
FOOTPATH
SHELTER FOR PASSENGER
R30000
R30000
SHOULDER
DRAIN
4500
7500
PARAPET
PLAN
SHOULDER
NATURAL SLOPE LINE
SLOPE TO SUIT THE TYPE OF MATERIAL MET WITH
600
PARAPET
SHED
DRAIN
7500
4500
1500

Fig. 9.4 Layout of Pick-Up Bus Stop Lay-Bye in Hilly Areas (dimensions in mm.)

Note:

1. *Adequate facilities for efficient drainage of the bus stop area including lay-byes should be ensured.*
2. *Pavement markings should be provided as indicated on the drawing. The word bus should be written on the pavement at the entry to the bus way for detailed guidance see IRC:35.*
3. *In the bus stop area the shoulder on bus stop side should be raised to from footpaths as marked on the drawing. The junction between shoulder and footpath should be suitably transitioned by a ramp.*
4. *For detailed guidance about location, layout, design etc. of bus stops refer IRC:80*

9.4.4 In all these developments, emphasis should also be laid on aesthetics, environment protection and blending of the facility with the landscape. Land for this purpose should be acquired at the time of land acquisition for the road itself. However while planning such facilities, it should be sufficiently distanced in case of any intersection, Toll Plaza, Railway Level Crossing, ROB / Grade Separator, etc. keeping in view of the safety requirements. Tentative distance to be followed in such cases are as per **Table 9.1**.

Table-9.1 Tentative Distance to be followed

Sr. No.	Item	Retail Outlet in Mountainous Section	Properties other than Retail Outlet and Individual Residential Property*
1	Acceleration and Deceleration lane	The Acceleration and Deceleration lane may be dispensed with for the fuel station located along urban roads and roads in hilly and mountainous terrain.	There shall be no direct access to the National Highways. The access shall be through the service road which will include acceleration and deceleration lane. Further all criteria mentioned in column (3) for Fuel station shall be fulfilled.
2	Intersection with any category and Median Gap	100 m	
3	Any Barrier including that of Toll Plaza and Railway Level Crossing	1000 m	
4	Start of approach of Road Over Bridge (ROB)	200 m	
5	Start of approach road of Grade Separator and Flyover	300 m	
6	Distance between two fuel stations	300 m for both divided and undivided carriageway and	

** such as Industrial Units, Hotels, Motels, Hospitals, Schools etc.*

9.4.5 To maintain cleanliness and hygiene, it is necessary to provide public toilet and washing facilities in every 75 km of the hill road section. There should be separate amenities for men and women. Proper arrangement of hot water, wash basin, toilet paper shall be available. In case of Religious/pilgrims route the distance between each public toilet shall be reduced by 50 km. In every 25 km it is recommended to have clean and hygienic toilet facilities. Toilet complex should also be planned with provision for physically challenged person.

9.5 Traffic Aid Posts/Emergency Medical Services/Communication System

9.5.1 *Traffic Aid Posts*

A major problem in hill roads is the absence of mobile network or suitable communication and assistance to aid the stranded and damaged vehicles and passengers in case of accident or breakdown. It is suggested that a system of ground traffic aid post with telephone/wireless communication be provided along all highways. This may be provided @60km all along the highways. Traffic Aid Post will comprise of round the clock 1 (one) mobile crane having the capacity to lift a truck with a Gross Vehicle Weight of 30,000 (thirty thousand) kilograms for promptly removing any damaged vehicles and its debris from the Project Highway to enable safe movement of traffic and shall report all accidents to the police forthwith. This should also have one dozer / excavator to remove the any debris / slide material from the site. The traffic aid post will also work as central command center for traffic management of the stretch. Traffic aid post should be located preferably in the middle of the stretch or at the Toll Plaza location. The traffic aid post should be fully equipped with Toilet facility, round the clock water supply facility and electrical supply with its fittings.

9.5.2 *Emergency Medical Services*

These services shall include providing a two patient capacity rescue ambulance (s) and setting up medical aid posts by the contractor / concessionaire at the Traffic aid post location. Traffic aid post and medical aid post should be at the same location with a minimum carpet area 150 m^2 combined for both traffic aid post and medical aid post.

9.5.3 *Communication System*

Emergency call box centres shall be established along the highways preferably @10 km. The entire stretch should be covered with OFC network wiring to enable the functioning of emergency call box centres and communication systems established.

9.6 Information Signs

One of the most important amenity to a traveler is availability of adequate travelling information. Adequate number of road signs in accordance with IRC:67 ”Code of Practice of Road Signs” should be provided on all roads. Also information sign boards to indicate the road condition i.e. Road open/closed, expected time of opening etc. should be displayed at suitable locations, preferably sector wise. Weather information along the route also be added as this is vital for travelling public. Variable Message Sign (VMS) boards should be preferably installed for advance warning about the road and weather condition. At check posts additional amenities by way of tourist information, road maps etc. should also be provided. Similar information, in printed form should also be made available at roadside fuel stations and restaurants. Sign posting should be in English and other regional languages in accordance with the practice being followed on National Highways.

9.7 Truck Terminals/Parking Complexes

A major cause of increase in accidents is also the non-availability of adequate resting places for truck drivers and crew. To take care of this requirement, truck parking complexes should be set up at convenient locations at a distance of about 100-120 km on or selected major arterial routes and such complexes should have facilities for parking, refueling, carrying out of repairs, supply of spare parts, canteen, board and lodge etc.

9.8 Eating Places

A major problem in hill roads is absence of clean and suitable eating places and the encroachment by small establishments on to the road. To solve the problem, suitable locations along the highway should be developed and leased to the operators at low cost. Such places should be kept well away from the right of way and should be provided with off-road parking facilities. Control should be exercised on them to improve the hygiene with the cooperation of local bodies and health authorities.

9.9 Coordination in Planning Amenities

Roadside amenities should be developed in coordination with other related departments like the Department of Tourism, Department of Telecommunications, State Transport Undertakings, Automobile Association, Transport Operators and ascertaining views of public through local Non-Governmental Organizations. Private sector participation for development of scenic spots, water points, shelters at but stop etc. with permission for display of their advertisements as per approved pattern could be considered so as to meet the cost of these amenities.

10. SAFETY AND TRAFFIC CONTROL MEASURES ON HILL ROADS

10.1 General

10.1.1 The safety of hill roads is an essential part of highway engineering. This involves appropriate decision on administration, design, construction, safety, maintenance, and operations including traffic management. It is aimed at setting standards which will produce desired degree of mobility and reduce the crash risks.

10.1.2 The provision contained in this chapter for safety on Hill Roads and Traffic Control Measures have to be mandatorily followed in all construction and maintenance contracts and should be an integral part of Detailed Project Report (DPR).

10.1.3 It must always be borne in mind, that safety on a hill road may be enhanced through implementation of laid down geometric standards, specifications, proper placement of essential traffic signs, markings and also adherence to traffic rules while negotiating the hilly terrain. Any compromise on these aspects, for financial or other considerations will only result in road with sub-standard safety norms. It is always preferable to build roads in adherence to the standardized safety norms, rather than attempting improvements at a later date. In this regard, it is prudent to conduct Road Safety Audits (RSAs) at various stages (such as Preliminary Stage and/ or Detailed Design Stage) of the proposed road/ expansion before its execution. These audits are essential to understand the safety hazards when the road is re-built (in the case of capacity augmentation projects) or construction of new alignments.

10.2 Causes of Road Crashes on Hill Roads

10.2.1 Driving in hills, especially in adverse and inclement weather conditions, is a complex, difficult and tiring task. Road crashes may occur at places where drivers are required to negotiate a different road geometry or road side environment abruptly without any prior warning. Various scenarios which may affect safety on hill roads are mentioned below:

a) Travelling over sharp curve with restricted sight distance, leading to frequent deceleration and acceleration

b) Negotiating a curve with varying speeds (i.e. applying brake when entering the curve and accelerating at the exit)

c) Alternating entry from major valley into side-valley, crossing of streams by narrow bridges, causeways, etc.

d) Presence of steep grades and/ or alternating ‘up’ and ‘down’ grades to negotiate through high altitude

10.2.2 The engineer/ decision maker should, therefore, consider the usual driving errors and response of vehicles while designing a hill road to reduce stresses on drivers and provide him/ her with a safe riding experience. To accomplish the same, it is desirable to conduct RSAs in various stages conforming to IRC:SP:88 before the road is taken up for construction. This would help in reducing the risk of crashes on any new road or road taken for capacity augmentation, and thus help to enhance safety of all types of road users.

10.3 Safety on Hill Roads

10.3.1 As in case of plain and rolling terrains, safety on hill roads also depends on various factors namely, Driver, Vehicle, Road and Environmental Conditions. Additional emphasis should be given to the environmental factors as inclement weather conditions and its unpredictability in hilly areas may often result in disastrous incidents; for example, prolonged heavy rainfall in hilly areas may lead to landslides on many occasions (such as mud flow, rock fall, rolling boulders, etc.). During winter seasons, it is accompanied by snow-fall, snow-drift, avalanche, icing problems, fog, chilly wind, blizzards, etc. To address the above issues on hill roads, the safe system approach should be adopted to minimize the risk of fatal and severe injury crashes. The five pillars of the safe system approach include: safe roads & roadsides, safe speed, safe vehicles, safe road users, and effective post-crash care. These five pillars encompass different engineering, enforcement, education and emergency care measures. The present document deals with the engineering measures in detail, whereas the other measures of safety are described briefly.

10.3.2 Road condition plays a very significant part in road safety. Studies based on widespread scientific research involving analysis of road crashes, road safety audits and other proactive measures, have indicated the significance of periodic examination of road conditions and driver's reaction to highway situations for achieving enhanced safety on hill roads.

10.3.3 The elements of roadways that have a direct bearing on safety from the geometric design point of view include cross-section, vertical & horizontal alignments, access control, type of pavement surface, system lay-out of mid-block & intersection design, to name a few. In addition, the hill roads should have the requisite road signs, markings, erection of delineators and crash barriers mounted with retro reflective tapes at required locations to enhance safety. To achieve maximum benefit, these measures should be implemented in combination, which in turn, determines the level of safety in hill roads.

10.4 Engineering Measures

Considering the above, engineering measures to improve safety in hill roads can be classified into four aspects as under:

a) Geometric design measures dealing with adequate width, curve radius & sight distance, easy grade, etc.

b) Engineering design measures to deal with specific and exclusive conditions in hills. These include design and provision of good drainage system, slope protection and slope stability measures, parapet, metal beam crash barriers/ wire rope safety barriers, railings, avalanche control structures, rolling boulder buffer (netting), etc.

c) Traffic control devices such as pavement markings, signs, signals, road studs, delineators, advance public warning system such as Variable Message Sign (VMS), etc.

d) Maintenance and periodical safety audit along with the associated identification and removal of black spots on the road corridor, if any.

10.5 Enforcement Measures

There are laws for enforcing traffic and vehicle discipline, which are to be adhered by all road users. Strict enforcement of these laws by the appropriate authorities and deterrent action on violation can enhance safety level and the same are summarized below:

a) Over-speeding: Adherence to the posted speed limit.

b) Condition of the vehicle: The vehicle must be in mechanically fit condition to operate on hill roads.

c) Condition of driver: The driver should be physically and mentally capable & alert to drive on the hill roads. The driver should also have tenacity and toughness to withstand the rigor of climate expected in hilly terrain. There is a need for keeping a strict vigil over the menace of drunken driving.

d) Overloading: Overloading of vehicles (load carriers and passengers), travelling on bus top and overcrowding in driver's cabin must be strictly prohibited.

10.6 Education Measures

Consciousness among the users about the road condition and necessity to adopt safety measures should be imparted through appropriate awareness initiatives including distribution of pamphlets, mass media publicity, etc. Important messages such as "DON'T MIX DRINK AND DRIVING", "IT TAKES CARE FROM TWO DRIVERS TO AVOID AN ACCIDENT" and "SAFE DRIVING TECHNIQUES", etc. may be incorporated in training programs by traffic control and enforcement authorities. The participation of NGOs for erection of such slogan boards with their advertisements as per the approved patterns on the reverse of board may be considered.

10.7 Effective Post-Crash Care Measures

When people are injured in a collision, they rely on emergency first responders to quickly locate them, stabilize their injury, and transport them to medical facilities. Fatal and serious outcomes are directly related to how injuries resulting from road traffic crashes are handled immediately after the incident occurs, as well as on-going care and rehabilitation.

Improvement in effectiveness of post-care facilities can be done by training of first responders (including community members) and emergency medical services staffs. Deployment of ambulance fleet must be optimal along the highway, so that a road crash victim can be transported to nearest trauma care unit within golden hour. Providing adequate equipment for emergency response units and trauma units within hospitals also decreases chances of fatalities and serious injuries of crash victims. A detailed description on medical facilities is included in **Chapter 9** of this document.

10.8 Safety Analysis

For formulating safety measures on existing road system, it is necessary to collect data of road crashes and conduct safety analyses. These can be done with the following aids:

a) Preparation of "Black spot maps" wherein details of the road crashes including location, type, severity, seasonal occurrence, pedestrian involvement, night incidence, etc. are marked.

b) Preparation of accident report form as per IRC:53 "Road Accident Recording Forms A-1 and A-4".

c) Detailed study of black spots based on either number of accidents or accident rates, and fatality, indicating road geometry information (road width, obstruction, super elevation, etc.).

d) Collision diagram indicating type and nature of collision of vehicles, pedestrian involvements, if any, etc.

e) Traffic volume, Speed, Vehicular Composition, etc.

By analysing the above data as per normal traffic engineering practices, suitable remedial measures can be formulated.

10.9 Geometric Deficiency

10.9.1 *Inadequacies in Sight Distance*

Geometric deficiencies cover inadequacies in sight distance, horizontal curves, vertical curves, pavement width, gradients, setback distance/ vision berms, camber, super elevation, passing places, and lateral/ vertical clearance. Deficiency in any of these geometric features compromises the safety, and the extent of it depends on the severity of the inadequacy.

10.9.2 *Safety on Horizontal Curves*

Safety on individual horizontal curves can be improved by the following method:

a) Realigning the road to build up the requisite radius.

b) Improving sight distance by batter benching or vision berms.

c) Equipping the curve with adequate road signs as per IRC:67, delineators as per IRC:79, and road markings as per IRC:35. A typical picture of a curve treated with chevron signs and spring post is shown in **Fig. 10.1**.

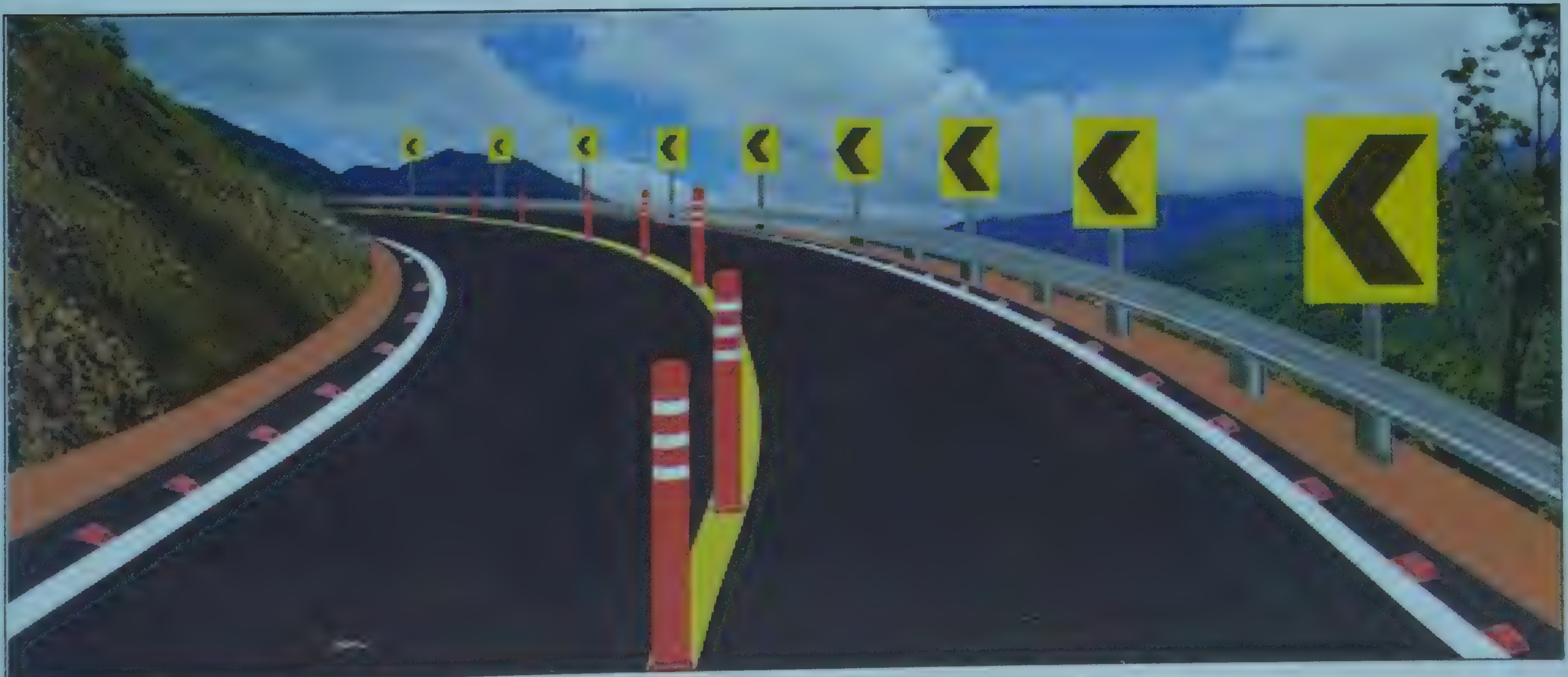


Fig. 10.1 Illustrative Sketch showing Locations of Chevron Signs and Spring Post on Curved Sections in a Hilly Terrain

d) Exploring the possibility of providing additional lane on blind curves and hairpin bends. Detailed measures are given in **Para 10.9.3.** Typical signage plan for hairpin bend is shown in **Fig. 10.16**, under **Para 10.9.6** of this document.

e) Ensuring that extra width at curve is invariably provided as per standards.

f) Providing parapets/metal beam/wire rope crash barriers at all dangerous locations.

10.9.3 *Narrow and Sharp Curves*

A common type of deficiency in hill roads is the existence of narrow and sharp curves, steep slope and zigs with inadequate sight distance. This leads to frequent head-on collisions. At such locations, the following measures should be taken:

a). A double solid centre line should be painted to prohibit overtaking in accordance with IRC:35 “Code of Practice for Road marking”.

b). Road studs/ cats eyes should be provided along the centre line on both sides of the road marking for providing enhanced visibility at night. Solar road studs should be provided at the valley side of the curve which is exposed to sunlight.

c). Parapet walls, guard stones and crash barriers along the valley side should be provided at all sharp curves. To improve night-time visibility of parapet walls, guard stones and metal beam crash barriers should be treated with Aluminium backed flexible prismatic retro-reflective sheeting as per IRC:79 consisting of yellow and black colour and is of size 300 mm x 300 mm.

d). The post of crash barrier should be treated with 3 bands of minimum 20 mm width retro reflective sheeting Type IV confirming to IRC:67. The typical application is illustrated in **Fig. 10.2**.

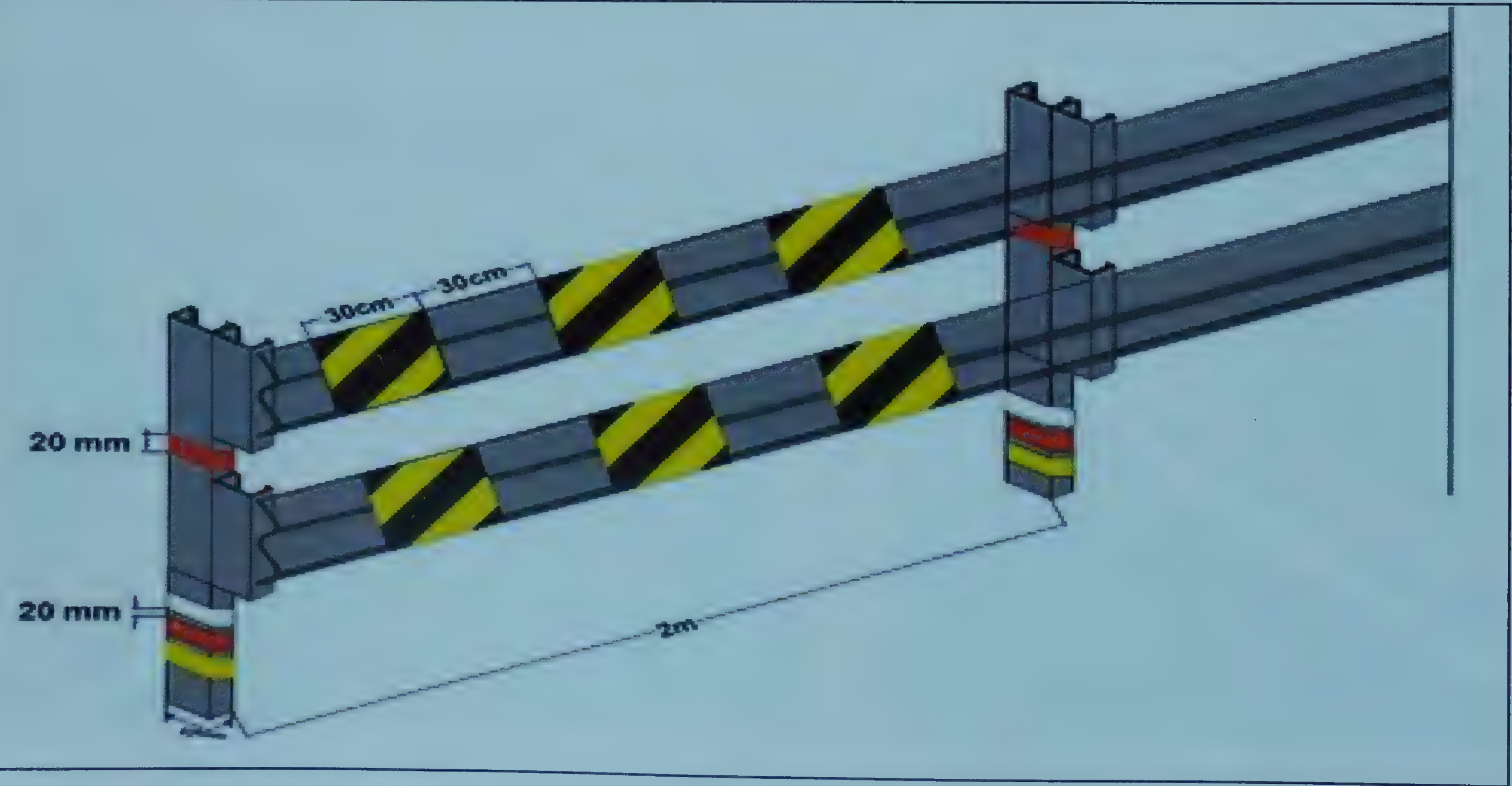


Fig 10.2a Reflective Sheeting Application on Double Beam Crash Barrier

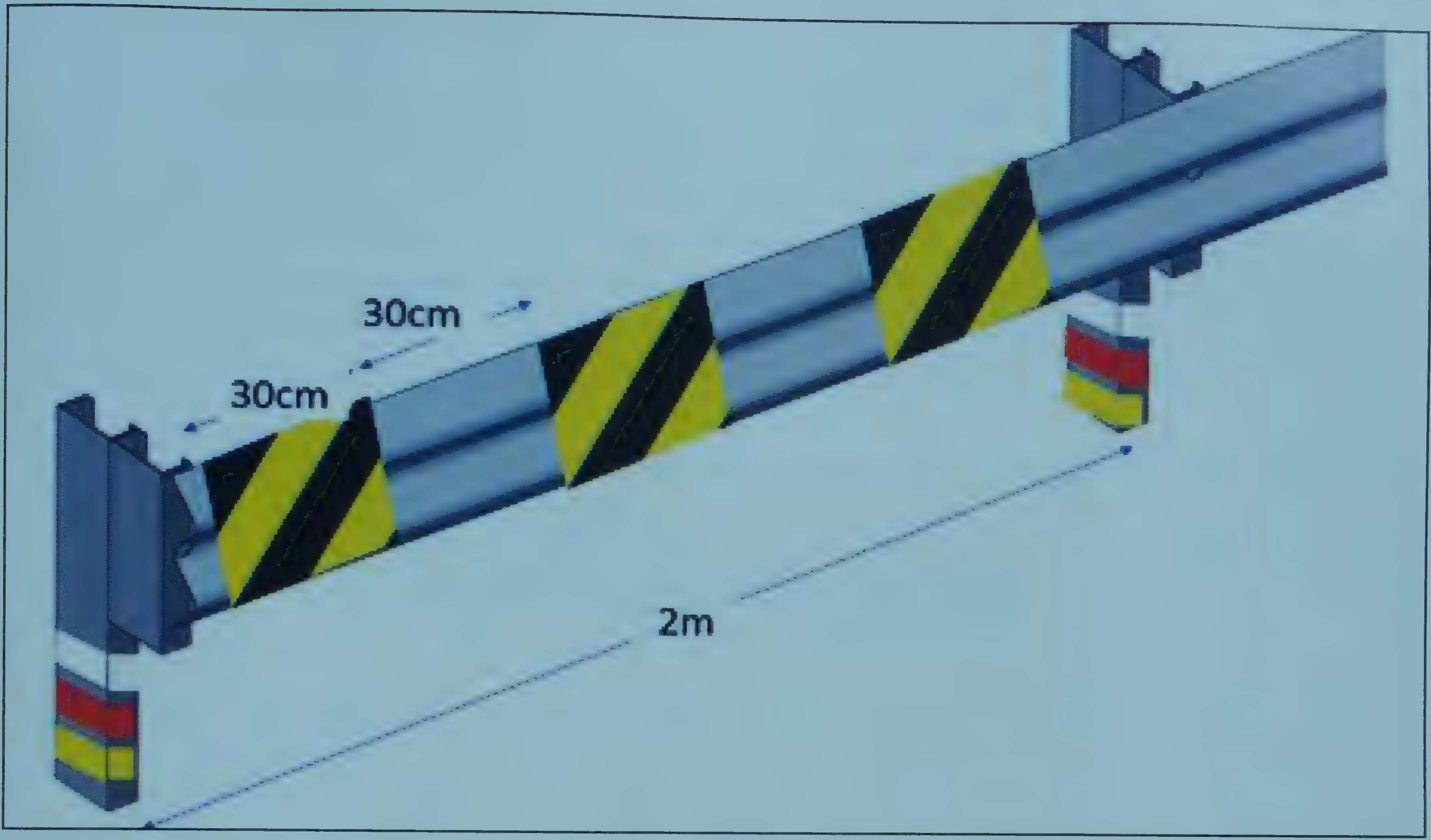


Fig 10.2b Reflective Sheeting Application on Single Beam Crash Barrier

Fig. 10.2 Retro-reflectorizing the Crash Barrier

e) OVERTAKING PROHIBITED', 'COMPULSORY SOUND HORN' and 'Speed Limit' signs should be placed on each side of curve in accordance with provision of IRC:67. Retro-reflective sheeting Type XI should be used on all signs to improve their visibility.

f) If feasible, as a long-term measure, adequate widening, transition curves and sight distance should be provided in accordance with the standards.

g) All the curves should be provided with curve warning sign in advance of hazard and chevron signs on the outer edge of the curve. The chevron sign is a vertical rectangle and installed always on the outside of a turn or curve, in line with and at approximately right angle to approaching traffic. Spacing of chevron signs should be such that the road user always has at least three signs in view, until the change in alignment eliminates the need for the sign as per IRC:67. Depending upon the sharpness of curve, single chevron, double chevron and triple chevron signs should be installed. If the deflection angle is more than 90 degrees, double chevron signs should be used. Triple chevron sign should be used at the hairpin bends as well as at the raised kerb of the central island of the roundabouts constructed at any intersection.

h) Further, as per IRC:79, the road delineator should be provided as an additional measure. The spacings are presented in **Table 10.3** under **Section 10.18.3** of this document.

i). All blind curves must have at least two lanes which should be divided by road marking and fixing of road studs/ cats eyes as per IRC:35. These blind curves should have measures in the form of installation of 'Hair Pin Bend', 'Sharp Curve Ahead', 'Speed Limit' and 'Crash Prone Area' signs conforming to IRC:67. While providing these signs, backing board concept using Fluorescent Yellow Type XI retro reflective sheeting as per ASTM D 4956 should be provided for achieving enhanced day and night time visibility. 'Crash Prone Area' Informatory signs should be placed ahead of the identified crash-prone location. It should also be in retro-reflective Type XI fluorescent yellow background with black symbols and numerals as shown in **Fig. 10.3**.

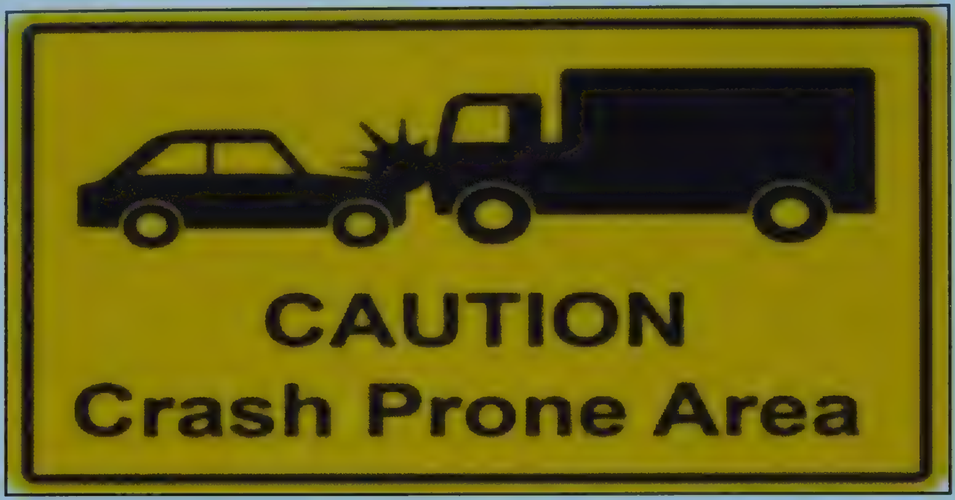


Fig. 10.3 Sign for Crash Prone Area

j). Cautionary Crash Prone Area Sign along with the speed limit sign in backing board as shown in **Fig 10.4** should be installed on approaches to the crash-prone sections.

10.9.4 *Vertical Curves and Grades*

In hilly areas, steep grades can contribute to large numbers of incidences of road crashes. This may occur due to factors such as insufficient sight distance, low capacity, interference to traffic on ascending grade and brake failure of the descending vehicles.

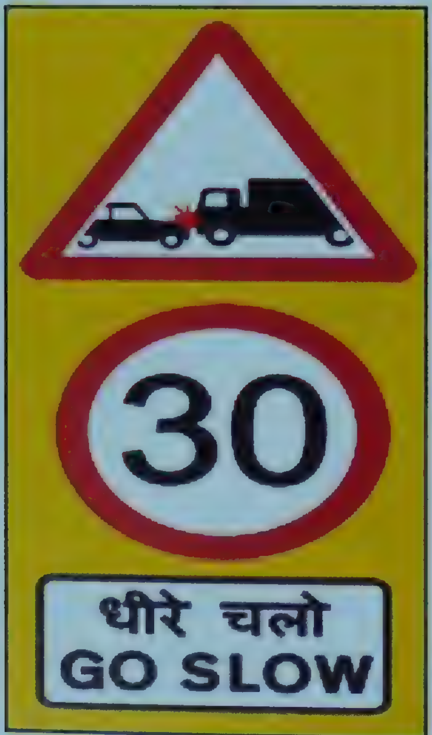


Fig. 10.4 Cautionary Sign for Crash Prone Area and Speed Limit Sign

10.9.4.1 Critical Length of Grades

For safe vehicular operation on hill roads, it is appropriate to consider the length of a particular grade according to desirable vehicle operation. Critical length of grade indicates the maximum length of a particular upgrade on which a loaded truck can operate without a significant reduction in speed. By providing length of a grade lesser than the critical value, a safe and acceptable operation in the desired range of speed can be expected. For expecting desired freedom of operation on grades longer than the critical length, other design adjustments must be incorporated such as reduction in grade, and/ or providing additional lanes, etc.

Determining factors: Three major factors influence the critical length of grade (As per AASHTO):

I. Size and power of a representative truck or truck combination to be used as a design vehicle along with the gradeability data for this vehicle.

II. Speed at entrance to critical length of grade.

III. Minimum speed on the grade below in which interference to following vehicles is considered unreasonable.

A typical loaded truck, powered so that the weight/power ratio is about 85 kg/kW (or sometimes 120 kg/kW for heavy trucks), is representative of the size and type of vehicle normally used as a design control for main highways. The average running speed as related to design speed can be used to approximate the speed of vehicles beginning an uphill climb. Where vehicles approach on nearly level grades, the running speed can be used directly. For a downhill approach it should be increased, and for an uphill approach it should be decreased. Traditionally, a reduction in truck speed of 25 km/h below the average running speed of all traffic has been used as a basis for obtaining critical length. However, the crash involvement rate increases significantly if the speed reduction is more than 15 km/h (2.4 times greater if speed reduction is 25 km/h instead of 15 km/h).

Studies show that the more a vehicle deviates from the average speed on the highway, the greater is its chance of involvement in crash (**Fig. 10.5**). It is recommended that 15 km/h reduction criterion be used as the general guide for determining critical lengths of grade.

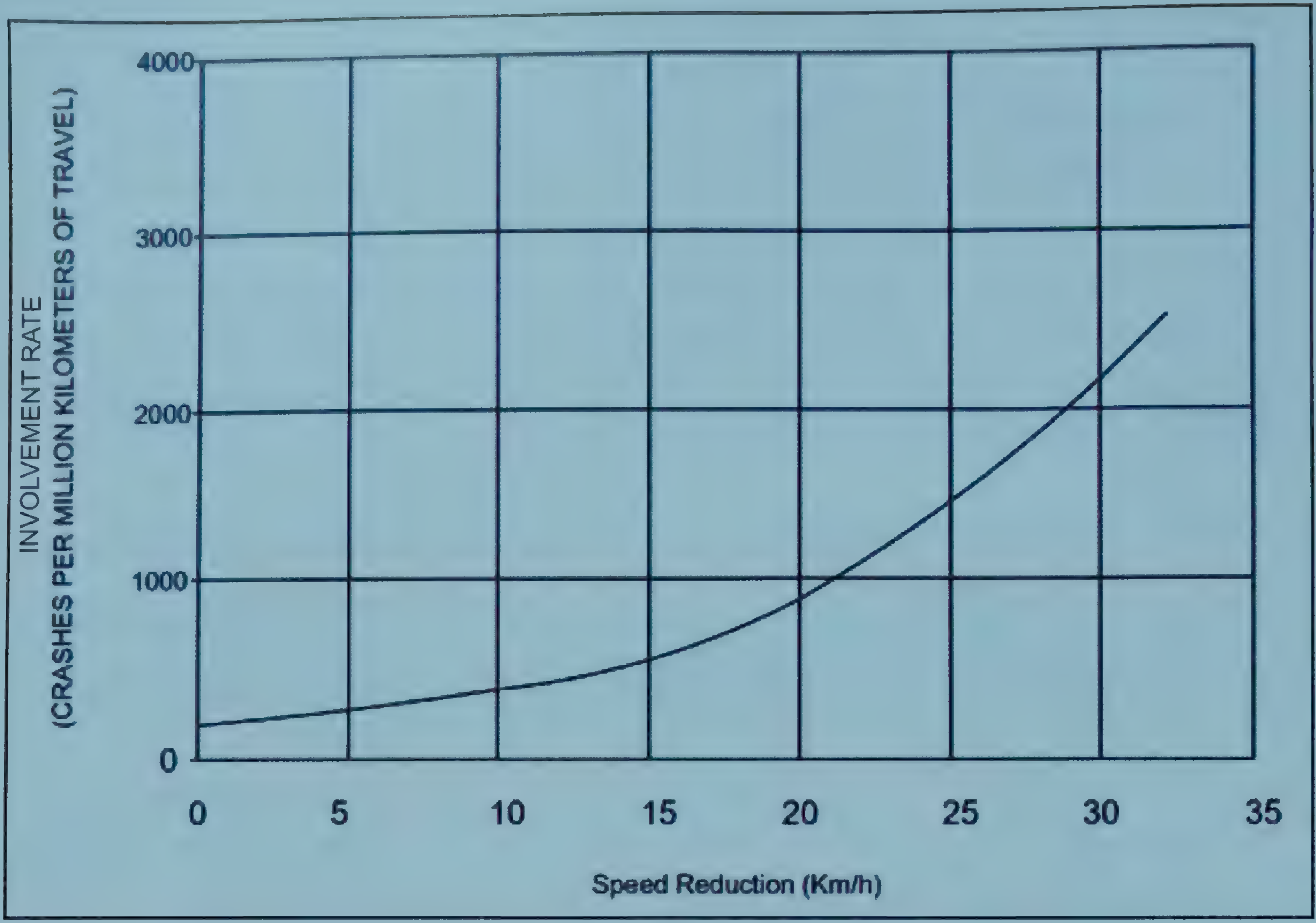


Fig. 10.5 Crash Involvement Rate of Trucks for which Running Speeds are reduced below Average Running Speed of all Traffic

The effect of rate and length of grade on the speed of a typical heavy truck with a weight/power ratio of 85 kg/kW are shown in **Fig. 10.6** and **Fig. 10.7.**

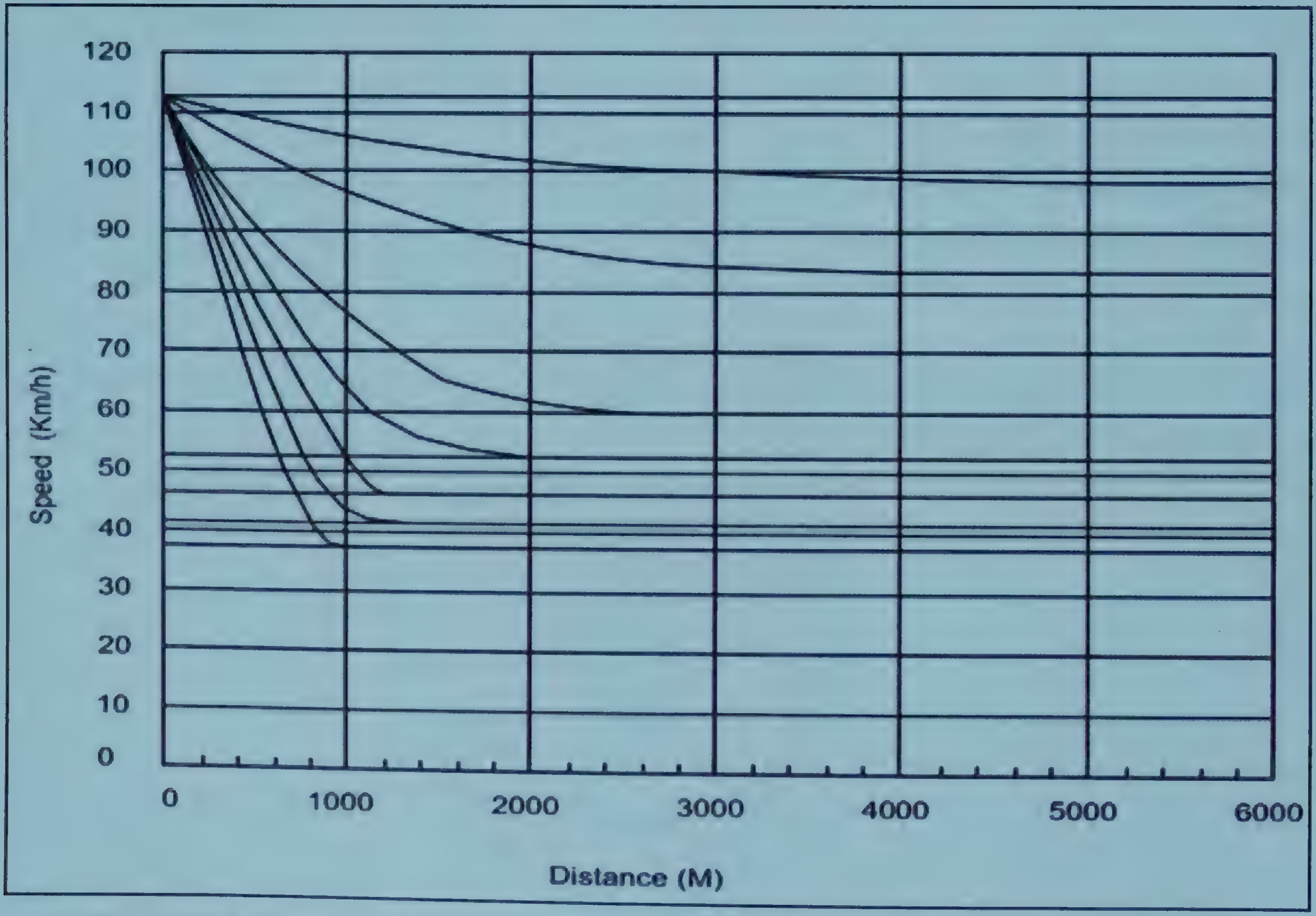


Fig. 10.6 Speed–Distance Curves for a Typical Heavy Truck of 85 kg/kW for Deceleration on Upgrades

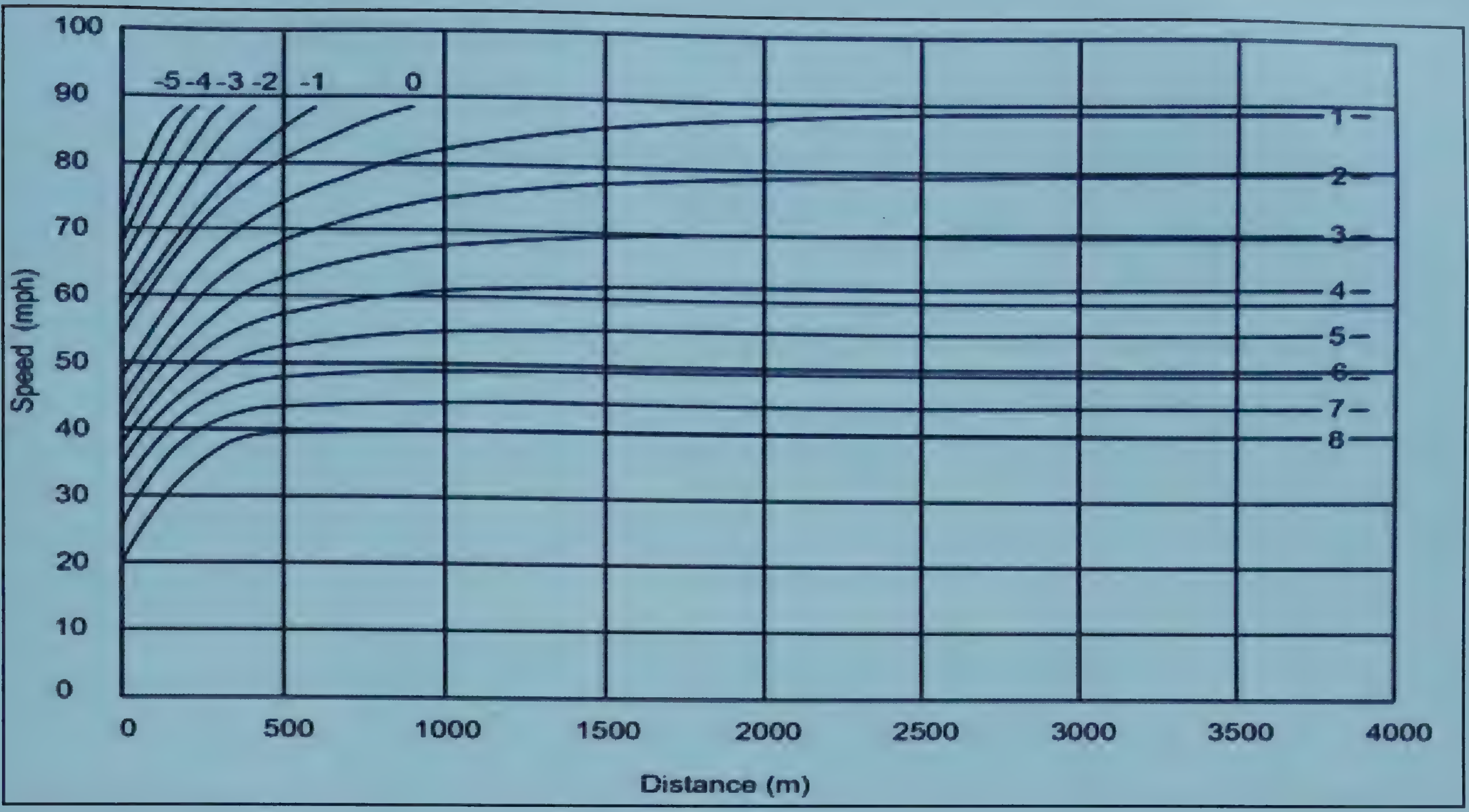


Fig. 10.7 Speed–Distance Curves for a Typical Heavy Truck of 85 kg/kW for Acceleration on Upgrades and Downgrades

The effect of rate and length of grade on the speed of a typical heavy truck with a weight/power ratio of 120 kg/kW are shown in **Fig. 10.8** and **Fig. 10.9**.

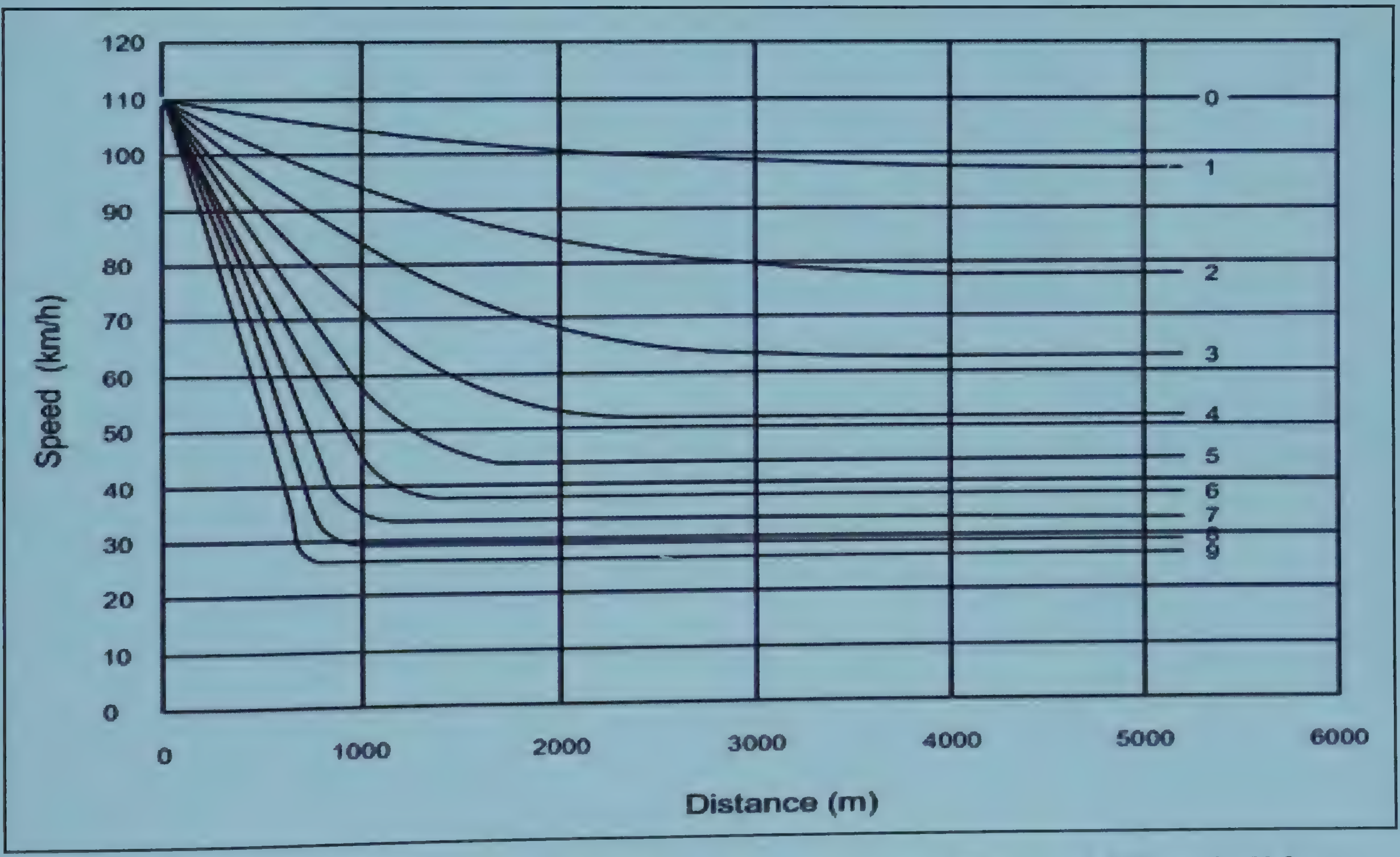


Fig. 10.8 Speed–Distance Curves for a Typical Heavy Truck of 120 kg/kW for Deceleration on Upgrades

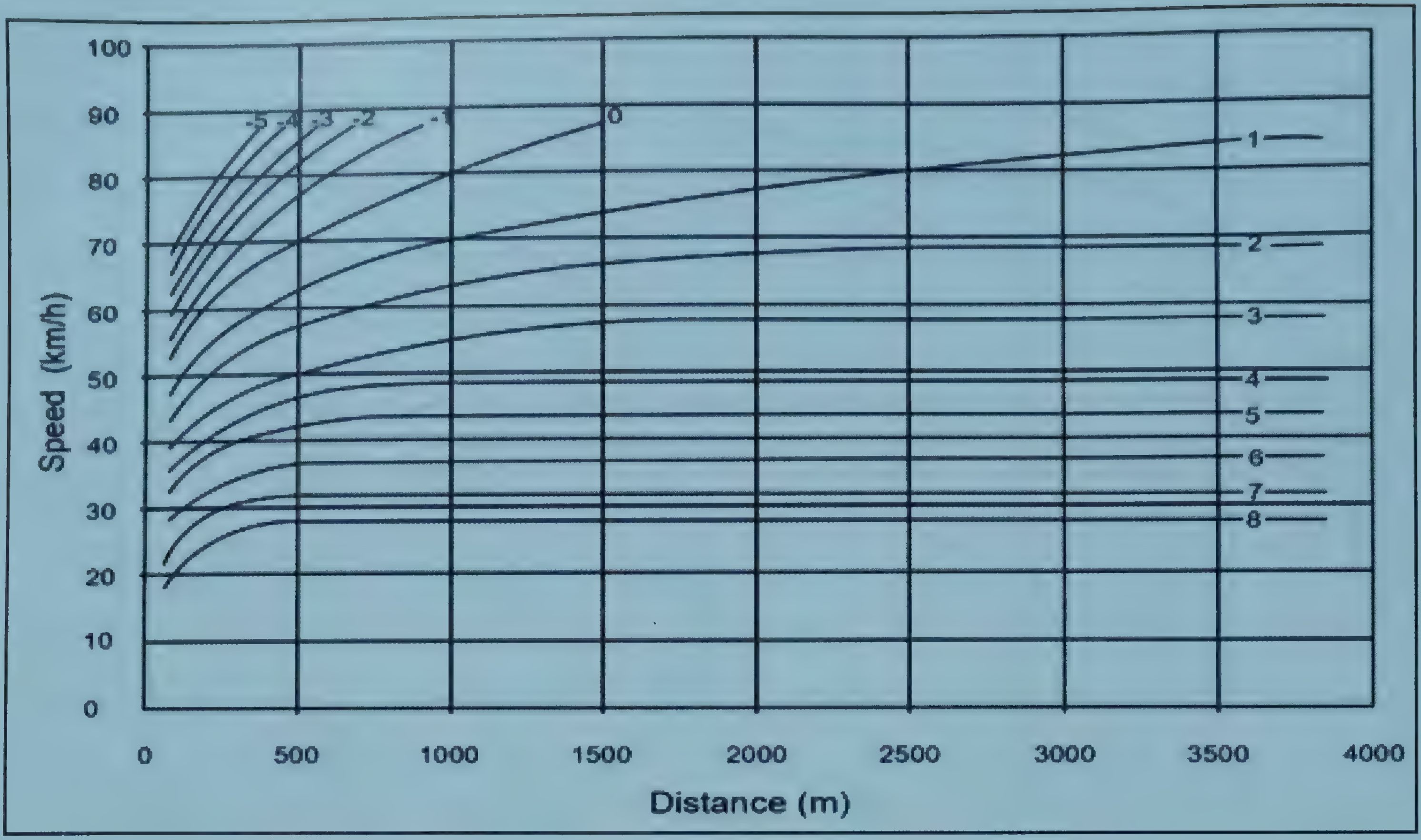


Fig. 10.9 Speed–Distance Curves for a Typical Heavy Truck of 120 kg/kW for Acceleration on Upgrades and Downgrades

When approach is on upgrade, speed reduction will occur over shorter lengths of grade and vice-versa. Where an upgrade is approached on downgrade, tolerable speed reduction may be increased to account for higher approach speed for trucks. The length of any given grade that will cause the speed of a representative truck (120 kg/kW) entering the grade at 110 km/h to be reduced by various amounts below the average running speed of all traffic is shown graphically in **Fig. 10.10**.

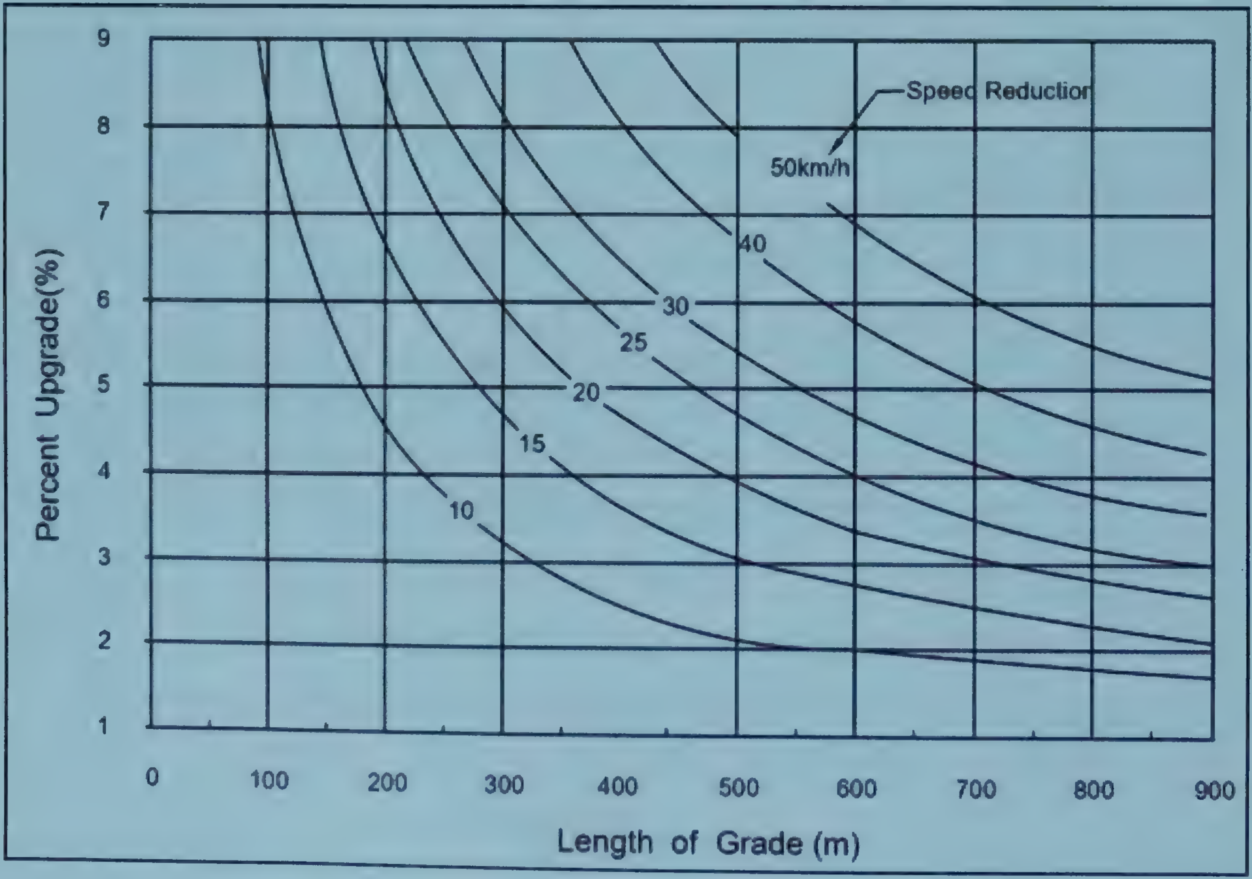


Fig. 10.10 Critical Lengths of Grade for design, assumed Typical Heavy Truck of 120 kg/kW, Entering Speed = 110 km/h

10.9.4.2 Climbing Lane on Ascending Grades

Safety of operation and freedom of movement on two-lane highways with an upgrade are affected by slow-moving vehicles such as heavily loaded trucks. For this purpose, an additional lane (also known as climbing lane) may be added for a particular stretch of road for such slow-moving vehicles uphill so that other vehicles using the normal lane are not delayed. It must be kept in mind that a two-lane highway with a climbing lane is not considered as a three-lane highway. Climbing lanes are designed for each direction independent of each other.

It is desirable to provide a climbing lane on a two-lane highway where the grade, traffic volume and heavy vehicle volume combine to degrade traffic operations as compared to the traffic condition before entering the grade. If the traffic volume is low and delay of cars is only occasional, climbing lane, although desirable, may not be economically viable. A typical illustration of climbing lane is shown in **Fig. 10.11.**

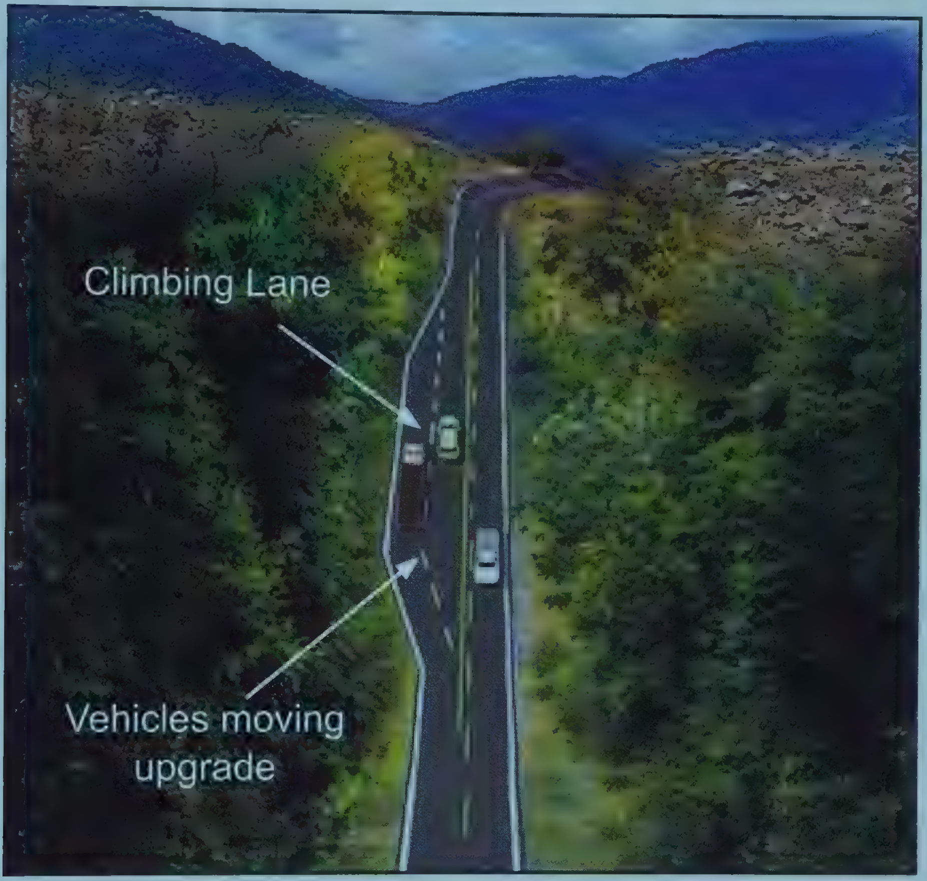


Fig. 10.11 Climbing Lane on Ascending Grade

Design Criteria: AASHTO Green Book on “A Policy on Geometric Design of Highway and Streets” suggests the following three criteria, based on economic considerations, which are required to be satisfied to justify a climbing lane:

I. Upgrade traffic flow rate more than 200 vehicles/hour

II. Upgrade truck flow rate more than 20 vehicles/hour

III. Existence of one of the following conditions:

    a). Expecting a reduction of 15 km/h or more in speed of a typical heavy truck

    b). Level of service E or F exists on the grade

    c). A reduction of two or more levels of service is experienced while moving from the approach segment to the grade.

In addition, if frequent crashes are experienced on the grade, irrespective of the grade or traffic volumes, climbing lanes are justified to construct.

Location Selection: The locations where climbing lanes should begin, depend on speed at which trucks approach the grade, and extent of sight distance restrictions on approach. In absence of any sight distance restrictions or other conditions that limit speeds on the approach, the climbing lane may be introduced on the upgrade beyond its beginning.

The 15 km/h decrease in truck speed below the average running speed is the accepted basis for determining the location at which a climbing lane should begin. With a downgrade approach, 15 km/h speed reduction would occur at longer distance and, with an upgrade approach, they would be shorter. Distances thus determined may be used to establish the starting point of a climbing lane.

Where restrictions, upgrade approaches, or other conditions indicate the likelihood of low speeds for approaching trucks, the climbing lane should be introduced near the foot of the grade. The beginning of the climbing lane should be preceded by a tapered section with a desirable taper ratio of 25:1 that should be at least 90 m long.

The ideal design is to extend a climbing lane to a point beyond the crest, where a typical truck could attain a speed that is within 15 km/h of the speed of the other vehicles with a desirable speed of at least 60 km/h. Where this is not possible, a practical point to end the climbing lane is where trucks can return to the normal lane without undue interference with other traffic. An appropriate taper length should be provided to permit trucks to return smoothly to the normal lane.

10.9.4.3 Escape Ramp on Descending Grades

On long descending grades, emergency escape ramp is desirable for out-of-control vehicles, particularly trucks, to slow and stop safely. Out-of-control vehicles are generally the result of a driver losing braking ability either through overheating of the brakes due to mechanical failure or failure to downshift at the appropriate time. A typical illustration of an escape ramp is shown in **Fig. 10.12.**

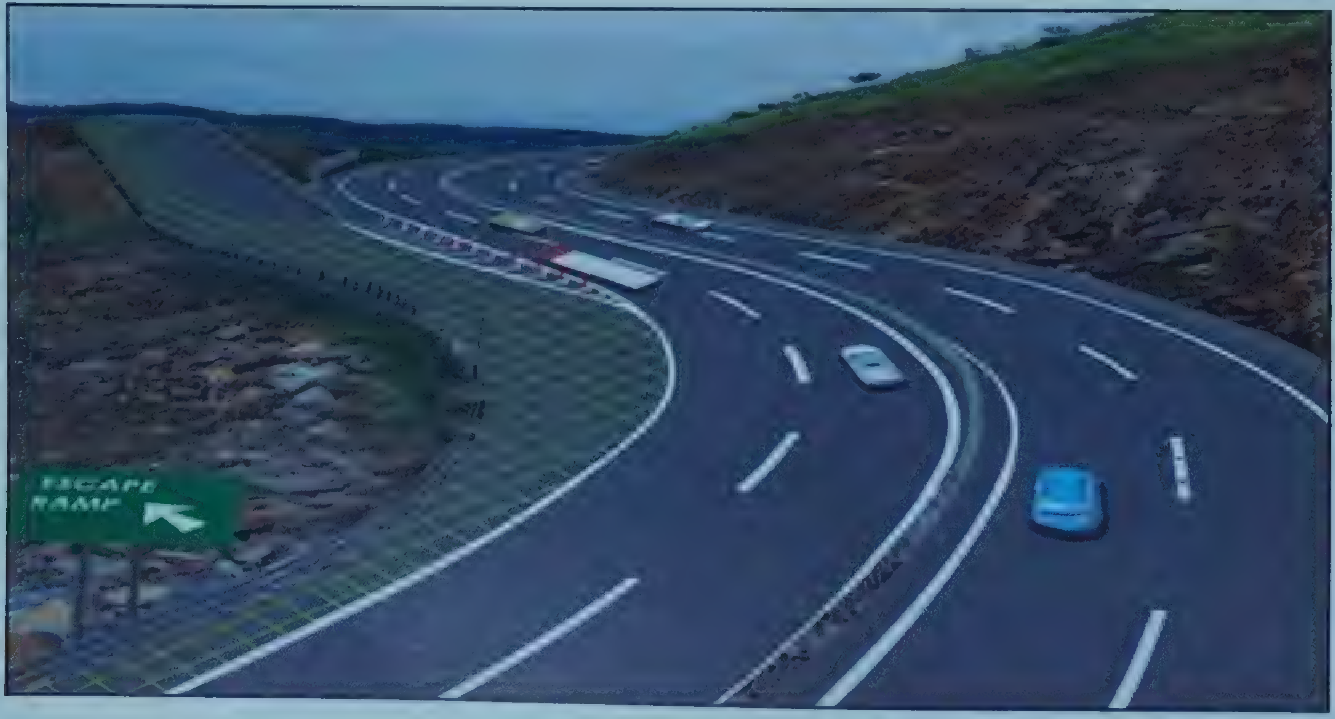


Fig. 10.12 Escape ramp on Descending Grade

Location Selection: AASHTO recommends the principal factor in determining the need for an emergency escape ramp should be the safety of the other traffic on the roadway, the driver of the out-of-control vehicle, and the residents along and at the bottom of the grade.

The factors which are considered for selecting the escape ramp are: Topography, length and percentage of grade, potential speed, availability of fund, environmental impact, and historical crash record. Ramps should be located to intercept the greatest number of runaway vehicles, such as at the bottom of the grade and at intermediate points along the grade where an out-of-control vehicle could cause a severe crash. Emergency escape ramps should be built in advance of horizontal curves that cannot be negotiated safely by an out-of-control vehicle and in advance of populated areas.

Forces Acting on a Vehicle: In general, three types of forces act on a vehicle affecting its speed on a grade, namely 'engine', 'braking' and 'tractive' resistance. It is better to ignore the engine and braking resistances as the ramp should be designed for worst case (i.e., vehicle is out of gear and brake system has failed). Tractive resistance comes from inertia, aerodynamic forces, rolling resistance and gradient. While inertial resistance and negative gradient act to maintain a vehicle in motion, rolling and positive gradient act to overcome inertial resistance. Aerodynamic resistance is generated from the retarding effect of air on various surface of the vehicle. Air resistance becomes significant at speeds above 80 km/h, but is negligible under 30 km/h. Rolling resistance is used to describe the resistance to motion at the area of contact between vehicle's tires and roadway surface (expressed as kg/1000 kg of gross vehicle weight). Rolling resistance offered by different surfacing materials are mention in **Table 10.1** (as mentioned in AASHTO).

Table 10.1 Rolling Resistance of Roadway Surfacing Materials

Surfacing Material	Rolling Resistance (kg/1,000 kg GVM)	Equivalent Grade (%)(Rolling resistance expressed as equivalent gradient)
Portland cement concrete	10	1.0
Asphalt concrete	12	1.2
Gravel, compacted	15	1.5
Earth, sandy, loose	37	3.7
Crushed aggregate, loose	50	5.0
Gravel, loose	100	10.0
Sand	150	15.0
Pea gravel	250	25.0

Types: Generally, three types of emergency escape ramps may be constructed: Gravity, Sand-pile and Arrester bed. The gravity escape ramps are paved or densely compacted aggregate surface, relying primarily on gravitational forces to slow and stop the runaway (such ramps are least desirable). Sand-pile ramps are composed of loose, dry sand dumped at the ramp site, are usually no more than 120 m in length.

In case of arrester beds, rolling resistance is increased by loose aggregates (such ramps are most desirable and effective in arresting out-of-control vehicles). These arrester beds may be laid either on a descending grade, or horizontal grade or ascending grade. The most commonly used escape ramp is the ascending type with an arrester bed, **Fig. 10.13.**

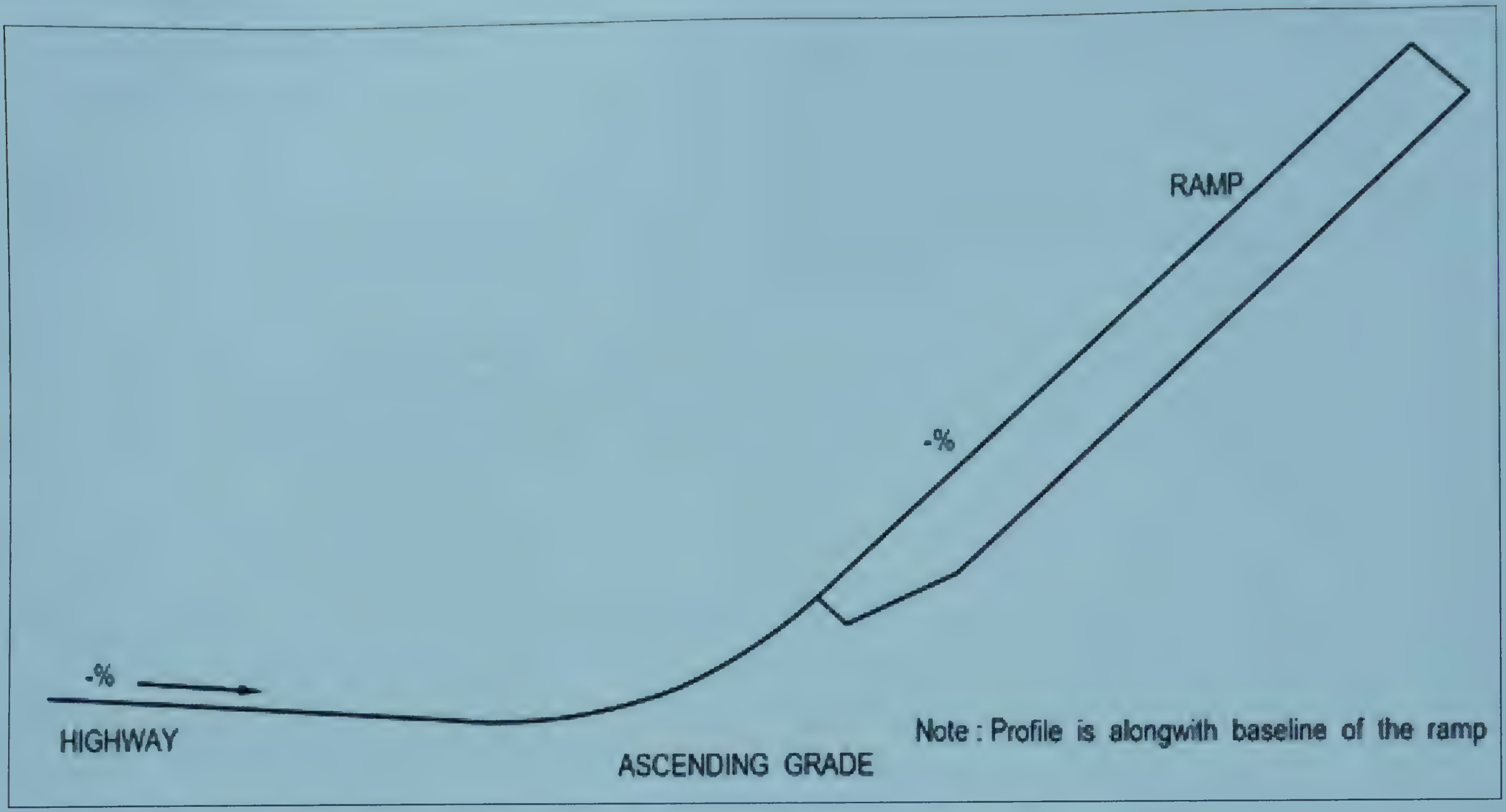


Fig. 10.13 Typical Type of Emergency Escape Ramp

Length of Arrester Beds: When a vehicle rolls upgrade, it loses momentum and will eventually stop due to the effect of gravity. The following equation may be used to calculate the distance required to bring the vehicle to a stop with consideration of the rolling resistance and gradient resistance:

$$L = \frac{V^2}{254(R \pm G)}$$

Where, L = length of arrester bed, m; V = entering velocity, km/h R = rolling resistance, expressed as equivalent percent gradient divided by 100 (as given in **Table 10.1**); G = percent grade divided by 100.

Recovery anchors are needed to secure the tow truck when removing a vehicle from the arrester bed. A typical layout of emergency escape ramp is shown in **Fig. 10.14**. When an arrester bed is constructed with more than one grade along its length (as shown in **Fig. 10.14)**, the decrement in speed occurring on each of the grades as the vehicle traverses the bed should be calculated using the following equation.

$$V_f^2 = V_i^2 - 254L(R \pm G)$$

Where: V_f = speed at end of grade, km/h; V_i = entering speed at beginning of grade, km/h; L = length of grade, m; R = rolling resistance, expressed as equivalent percent gradient divided by 100 (as given in **Table 10.1**); G = percent grade divided by 100.

The final speed for one section of the ramp is subtracted from the entering speed to determine a new entering speed for the next section of the ramp. The calculation must be repeated at each change in grade on the ramp until sufficient length is provided to reduce the speed of the out-of-control vehicle to zero.

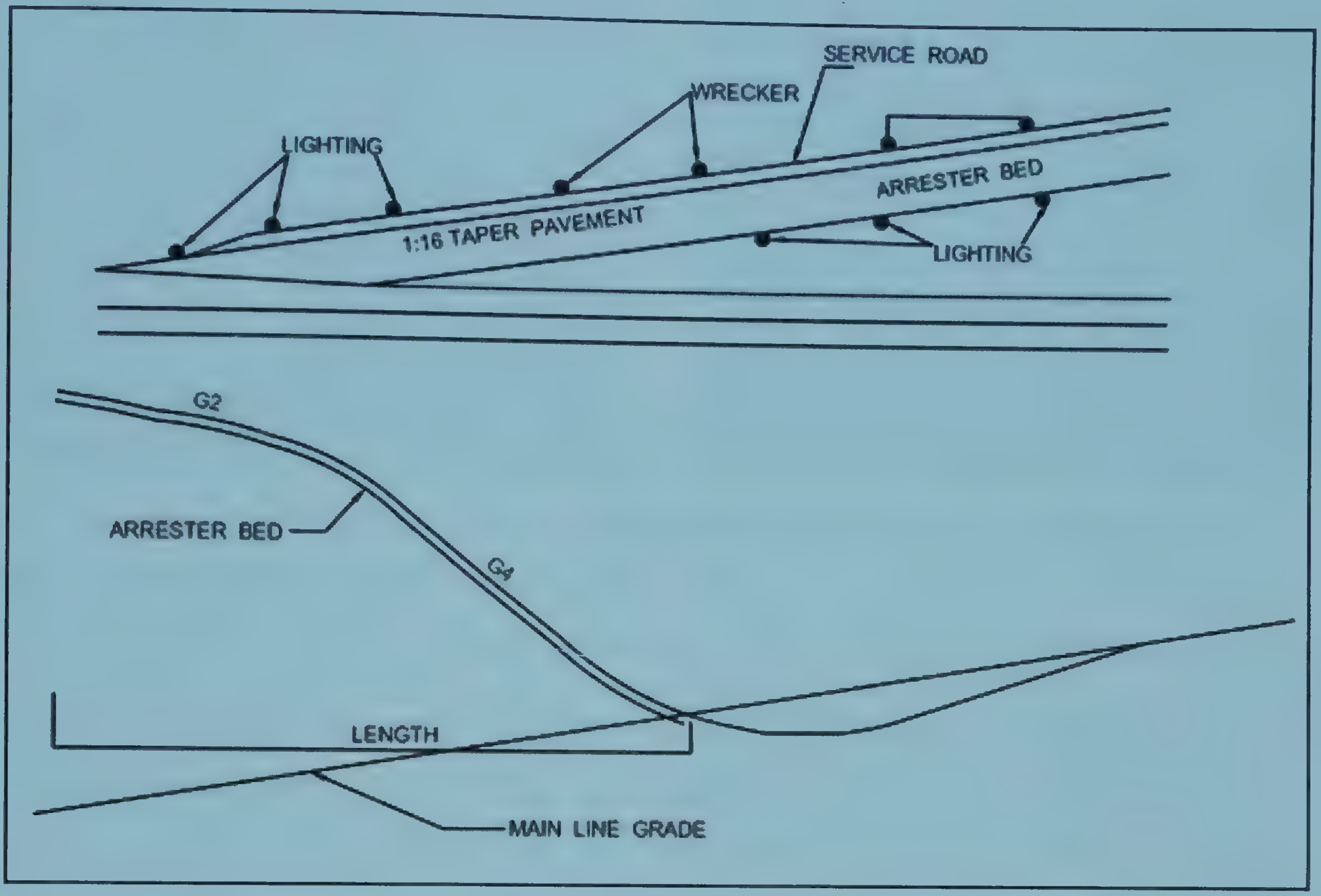


Fig. 10.14 Layout of Emergency Escape Ramp (Left Hand Drive)

Escape lanes should exit from the left side of the main lane. A brief detail on the design aspects of escape ramps is mentioned in IRC:52. For new and existing facilities and until local criteria are available, it may be useful to adopt the AASHTO criteria.

Design Criteria: Escape ramp should be designed for speed range of 50 to 120 km per hour. Design of escape ramps should be followed as per the criteria described in **IRC: 52**.

10.9.4.4 General Controls for Vertical Alignment

For safe operation on vertical curves, the following conditions must be kept in mind while designing:

- Horizontal and vertical alignment should not be designed independently. They must complement each other because poorly designed combinations can spoil the good points and aggravate the deficiencies of each.
- Excellence in the design of each and of their combination enhances vehicle control, encourages uniform speed, and improves appearance, nearly always without additional cost.
- Sharp horizontal curvature should not be introduced at or near the top of a pronounced crest vertical curve.

- Sharp horizontal curvature should not be introduced near the bottom of a steep grade approaching or near the low point of a pronounced sag vertical curve.
- A smooth grade line with gradual changes is preferable to a line with numerous break and short lengths of grades.
- The "roller-coaster" or "hidden-dip" type of profile (short vertical curves within a continuous profile) should be avoided by the use of horizontal curves or by more gradual grades.
- A "broken-back" grade line (two vertical curves in same direction separated by a short tangent) should be avoided and replaced by single curve.
- On long upgrades, it is not desirable to provide a uniform sustained grade that is only slightly below the recommended maximum. Instead, it may be preferable to place the steepest grades at the bottom and flatten the grades near the top of the ascent or to break the sustained grade by short intervals of flatter grade. This is particularly applicable to roads and streets with low design speeds.
- Where at-grade intersections occur on roadway sections with moderate to steep grades, it is desirable to reduce the grade through the intersection. Such profile changes are beneficial for vehicles making turns which would reduce the crash potential.
- Profiles at pedestrian crosswalks must consider limitations on cross slope so that the crosswalk is accessible to and usable by individuals with disabilities.
- Sag vertical curves should be avoided in cuts unless adequate drainage can be provided. Sag vertical curves at undercrossing should be designed to provide vertical clearance for the largest legal vehicle that could use the undercrossing without a permit.

10.9.5 *Bridge Approaches*

Another potential black spot location on hill road is the bridge location having curved approach combined with down gradient. Such locations are common sites witnessing toppling of vehicle over the bridge. Such design of bridge should be avoided, and bridge structure should follow the general flow of the alignment. However, short term measures to improve safety are to increase visibility by using cautionary signs with retro-reflective type XI sheeting as per IRC:67, use of speed control measures and strong guard rail to arrest out of control vehicles.

At the same time, if the crash barrier is used in normal section (straight portion), to improve the visibility, Linear Delineation System (LDS) with Type XI retro reflective sheeting should be provided as shown in the **Fig. 10.15**.

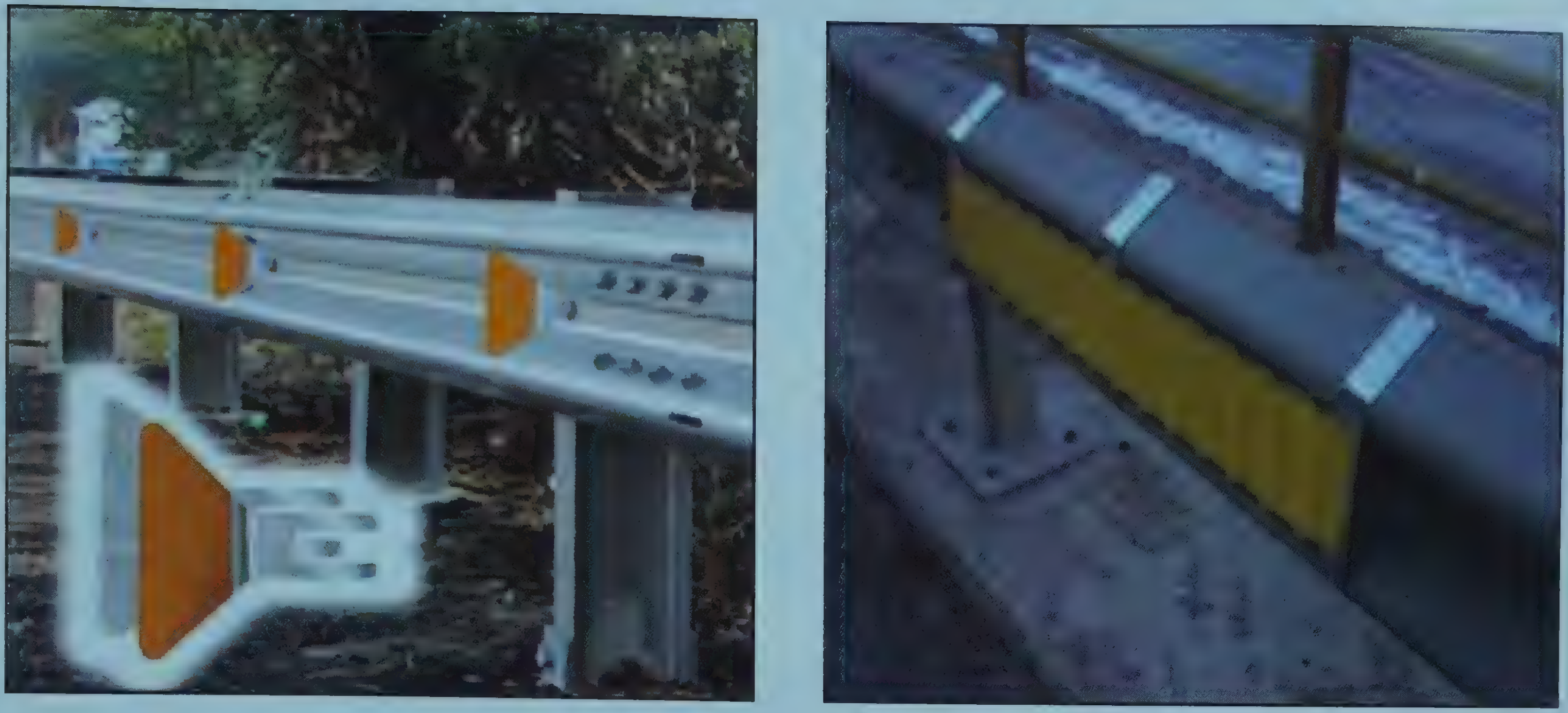
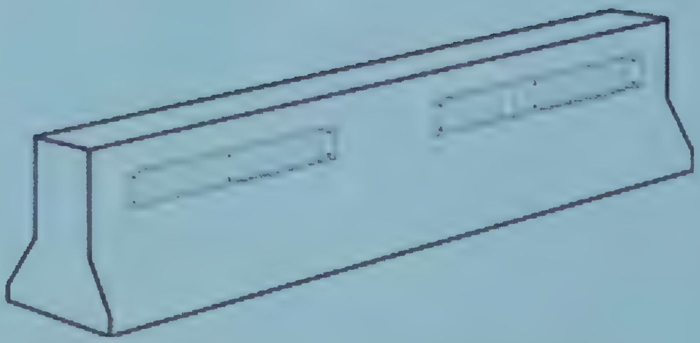


Fig. 10.15 Linear Delineation System

10.9.6 *Hairpin Bends*

Hairpin bend is a very critical section of a hill road. It is important to include all types of road safety signages, markings and road furniture. Also the compulsory sign of sound Horn as per IRC:67 "Code of Practice for Road Signs" shall be provided at critical locations like blind curve/hairpin bends (where stopping site distance is inadequate due to site constraint etc). **Fig. 10.16** shows typical sign plan for a hairpin bend.



10.10 Problem of High Altitude/Snow-Fall Areas

Snow-drifts and avalanches are common problems in high altitude and snow-fall areas. A detailed study of the phenomena and identification of sections prone to these problems need to be done. Having identified the areas, first a warning system must be installed and then long-term engineering measures must be planned. The engineering measures available are snow and avalanche control structure such as snow fences, snow bridge, snow sheds, snow gallery, etc. to allow passage of snow-drifts over the road and construction of tunnel, etc.

For a new road, if problems such as snow-drifts and avalanches are identified at the survey stage itself, then the possibility of the realignment of the road should be explored. Otherwise, the suitable avalanche control structures along with necessary protection should be incorporated at the design stage. Snow markers showing depth of snow should be placed on both sides of the road for guidance. These are dealt with in detail in **Chapter 6** "Snow Clearance and Avalanche Treatment".

Before approaching snow-fall area, Variable Messaging Sign (VMS) as per IRC:SP: 85 should be installed to get live information about weather condition, road closure advisory for using snow mobility accessories such as snow chain, etc. Weather station should also be installed and live data should be transmitted to road users through VMS.

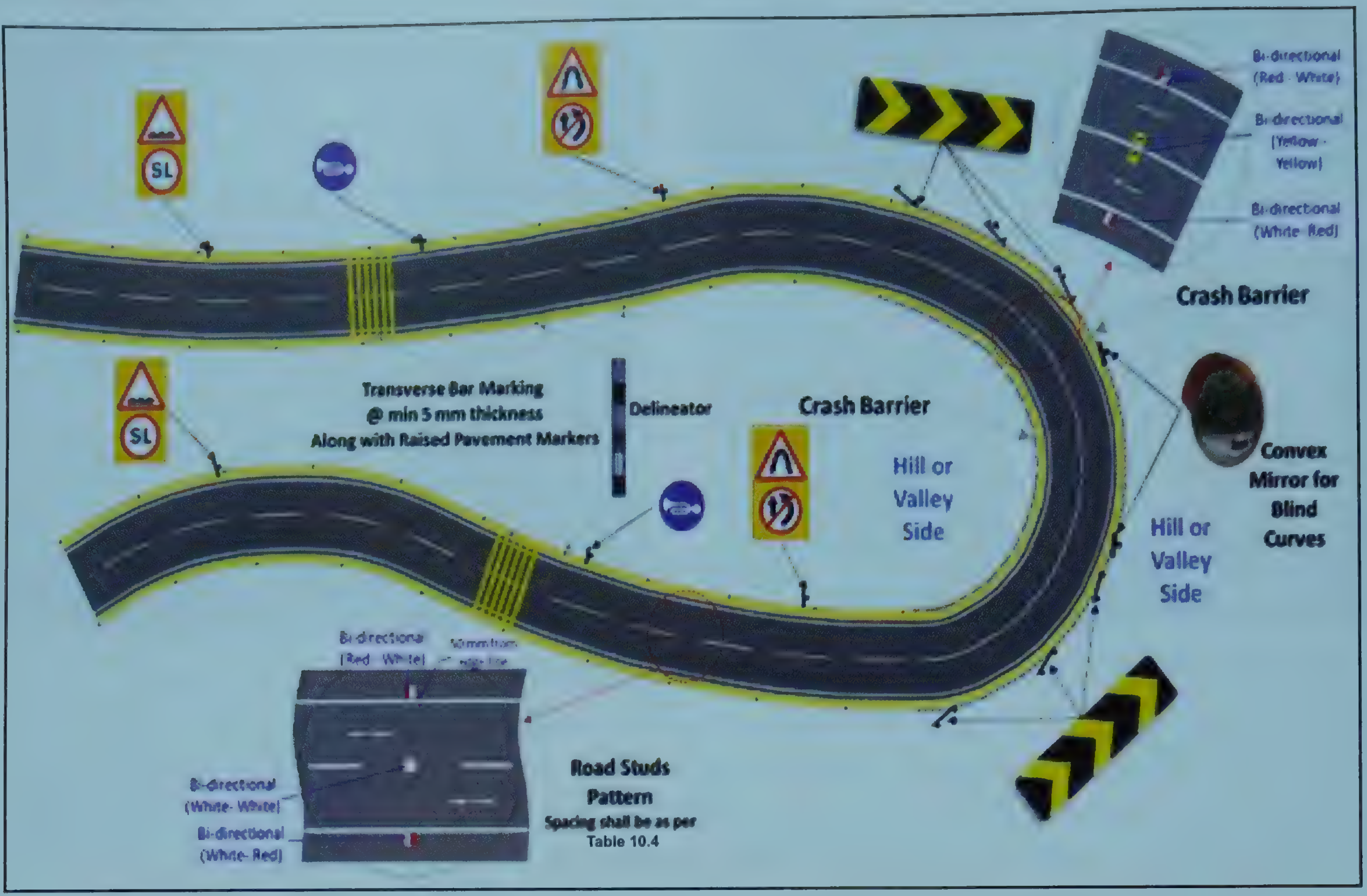

SL
SL
Transverse Bar Marking
@ min 5 mm thickness
Along with Raised Pavement Markers
Delineator
Crash Barrier
Hill or Valley Side
Hill or Valley Side
Bi-directional (Red - White)
Bi-directional (Yellow - Yellow)
Bi-directional (White - Red)
Crash Barrier
Convex Mirror for Blind Curves
Bi-directional (Red - White)
Bi-directional (White- White)
Bi-directional (White- Red)
Road Studs Pattern
Spacing shall be as per Table 10.4

Fig. 10.16 Typical layout of Hairpin bends

10.11 Rock Fall, Shooting Boulders, Unstable Areas etc.

10.11.1 A common cause for road crashes in some locations of the hill roads is shooting boulders or rock fall. This is basically due to unstable upper slope. Some of the measures to improve safety of such locations are detailed in **Chapter 6** and these have to be applied selectively depending on the situation. In addition to its application, it is essential to post appropriate warning sign, i.e., 'Rock Fall Area' as shown in **Fig. 10.17**. It should be erected at least 100 m before the identified hazardous location.

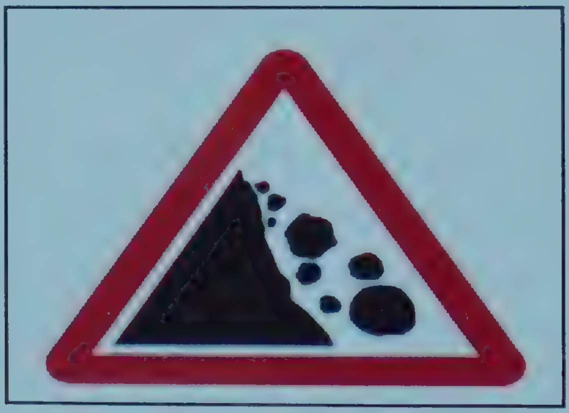


Fig. 10.17 Rock Fall

10.11.2 Slides, flow of excessive water and slope materials on the roads are common factors endangering safety on roads in hills during rainy season. Major slides block the road and smaller slides make the roads slushy and slippery. Overflowing water erodes the berms, jeopardizing safety. A combination of catch-water drains, chutes, catch pits with cross drains and adequate camber can channelize the drainage and improve safety on roads as discussed in the section 2 of this document.

10.12 Vehicle Rolling into Valley

Vehicle rolling off the road into the valley is also a major safety problem. In areas prone to this type of accidents, i.e., blind curves and deep vertical cuts, strong parapet walls/ metal beam/ wire rope crash barriers capable of restraining the vehicle back or guard rails/ cable fixed to deep piles or strong pillars should be provided at suitable intervals.

10.13 Low Visibility

In sections of roads subjected to serious visibility reduction due to fog, rain, low clouds and on sharp curves, road delineator should be provided in accordance with IRC:79. All the cautionary, advance warning and information signs in this low visibility area should be made of fluorescent yellow type XI sheeting backing board which has higher visibility and legibility in daytime as well as during dawn/ dusk. A typical bilingual (English and one local regional language) 'low-visibility area' sign-board should be used under such circumstances as shown in **Fig. 10.18**. Road markings must conform to both dry and wet retro reflection as per IRC:35 in order to improve day-time and night-time visibility. In addition, road furniture such as delineator, type VI flexible prismatic sheeting, category A type road studs, median marker, etc. should be effectively used on roads with low visibility to avoid the chances of road crashes.

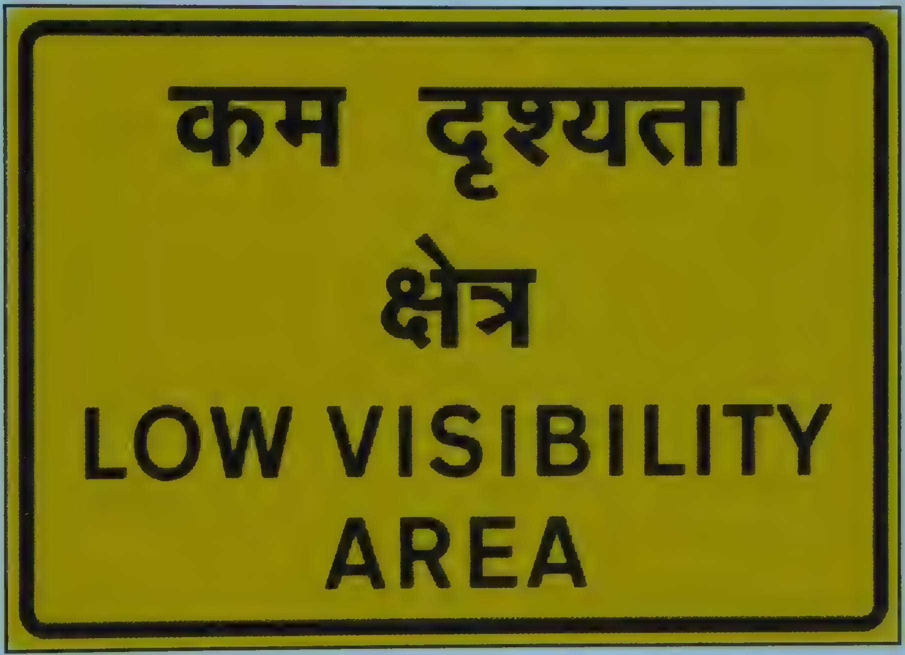


Fig. 10.18 Low Visibility Area Signboard

10.14 Icy Areas

10.14.1 In many locations of hill roads in high altitude areas, water over the road surface freezes into ice lenses which makes the roadway slippery causing accident by skidding. In such locations, the following measures should be adopted:

a) Install warning sign of "Slippery Road" (as per IRC:67), provide additional information signs advising use of tyre-chains and impose speed limits with supplementary plate or with fluorescent yellow backing plate.

b) At steep gradient, improve cross drainage towards hill side to prevent skidding of vehicle to valley side.

c) Provide impact resistance guard railing or parapet wall, metal beam, wire rope crash barrier, and delineator on valley side.

d) Use de-icing chemicals.

10.14.2 The problem of snow and ice has been dealt with in detail in **Chapter 6** “Snow clearance and Avalanche Treatment”.

10.15 Construction Sites

Construction sites on hill roads also pose a huge safety hazard unless suitable precautionary measures are taken considering the limitation of the terrain and Right of Way (RoW) available for re-routing of vehicles. Road signs such as ‘DEAD SLOW’, ‘WORK IN PROGRESS’, etc. should be placed well in advance of work zone site to warn the road users of the danger ahead. Traffic control devices such as traffic cones, spring post, drum barricades, etc. should be provided as per IRC: SP:55. Retro reflective flexible work zone sheeting used on these traffic control devices should be conforming to ASTM D 4956 clause S2 with type IV grade sheeting. While working on deep foundations, the area leading to work sites must be heavily barricaded and illuminated at night to prevent any errant vehicle falling in.

10.16 Ribbon Development

Ribbon development along highways in the form of encroachments, proliferation of places, roadside vehicle repair shop, etc. is a big menace which seriously impairs safe movement of vehicles. Such roadside development on the Right of Way (RoW) magnifies the safety issues on hill roads. Measures to control this problem involve removal of encroachments, provision of railings on road boundary, provision of separate laybys, places and way-side amenities available off the road at designated places. Provision of roadside amenities should be done as per IRC:SP:48. Further, approaches to such locations should be fortified with relevant type of cautionary & informatory signs (as mentioned in IRC:67) and speed calming measures (as mentioned in IRC:99), which would prevent the risk of road crashes. At such locations, relevant informatory sign, i.e., ‘Built up Area’ sign should be placed at 100 meters followed by at 50 meters before the start of such ribbon development coupled with placement of relevant cautionary signs at every 30 meters.

Locations where frequent interactions between vehicles and Vulnerable Road Users (VRUs) are expected, the posted speed limit must be restricted to 30 km/h considering human injury tolerance criteria. In case of locations with littler VRU involvements, speed limit may be set at 40 km/h considering the same criteria. In all such locations, even a lower speed limit may be adopted if the road geometry is deficient and demands a lower speed.

10.17 Miscellaneous

Roadside trees, poles, projecting rocks and parapets may also lead to accidents. A band of Aluminium backed flexible prismatic reflective sheeting consisting of yellow and black colour as per IRC:79 should be used to improve visibility of road side trees, poles, projecting rocks, parapets, etc. during the night-time.

10.18 Traffic Control Devices

10.18.1 *General*

Traffic control devices, road safety devices and roadside furniture should comprise of road signs, road markings, object markers, hazard markers, road studs, delineators, attenuators, safety barriers, pedestrian guard rails, boundary stones, km stones, etc. Guidelines given in IRC:8, IRC:25, IRC:26, IRC:35, IRC:67, IRC:79, IRC:103, IRC:SP:55 and Section 800 of MoRTH Specifications should be followed for providing these items unless otherwise specified in this section.

10.18.2 *Road Signs*

The three types of road signs viz., mandatory/ regulatory signs, cautionary/ warning signs and informatory signs should be provided as given in IRC:67. Proper signs should be provided for main carriageways, service & slip roads, toll plaza and other project highway facilities. Clustering and aggregation of road signs should be avoided for enhancing their effectiveness.

a) Corresponding road markings with stop signs, give way signs, merging or diverging traffic signs, lane closed signs, road narrowing signs, slip roads/ diversion signs, compulsory keep left/ right signs, or any other signs as per IRC: 67 should be provided.

b) The specifications and standards of any road signs which are not covered by IRC:67, may follow other International Standards.

c) All road signs should be made of Class C sheeting as described in IRC:67. The sheeting for different type of signs should be chosen based on the selection guidance provided in IRC:67, depending upon the situation encountered by road users in viewing the signs. Sheeting with high coefficient of retro-reflection at small observation angle is required for a road sign, when it is supposed to be viewed by a driver from a long distance, whereas the sheeting with wide observation angle is for better performing at short distance viewing. The type XI sheeting has better performance at short and medium distances. Micro prismatic type XI sheeting is preferred for gantry mounted overhead signs. Fluorescent yellow colour backing board should also be considered at necessary locations as they have higher day time luminance factors for all weather conditions including overcast and foggy/ rainy conditions.

d) Shoulder mounted signs should be supported on GI or MS pipes. Overhead signs should be placed on a structurally sound gantry or cantilever structure made of GI or MS pipes. Its height, lateral and vertical clearance for installation should be as per the guidance provided in IRC:67 and also as per Section 800 of MORTH Specifications.

e) Locations of overhead traffic signs should be specified in Schedule 'C' of the Concession Agreement. The following conditions may be considered while deciding about the locations of overhead signs:

   i) Present and future traffic volume

   ii) Restricted sight distance

iii) Built up stretches

iv) Insufficient space for placing ground mounted signs and where road features and roadside activities obstruct the ground mounted signs

v) Large percentage of commercial vehicles

vi) Distances of important places and routes at suitable intervals.

vii) Before major intersections of considerable traffic bifurcation and on approaches to interchanges/ flyovers/ Viaduct and Underpass (VUPs)

The overall size of gantry mounted signs should be decided based on design of sign boards given in IRC:67.

f) The road sign, traffic signal or any other device erected for traffic control, traffic guidance and/ or traffic information should not obstruct other traffic signs. Further, the signs and signals should not carry any advertisement.

10.18.3 *Signs for Curved Sections*

Wherever the Hill Road Project alignment is on a curve, there should be cautionary signs for sharp curves placed at least 50 to 75 m in advance (depending on whether it is on hill side or valley side) followed by the placement of chevron signs (rectangular in shape with fluorescent yellow background and black arrow) at the outer edge of the curve conforming to IRC:67. The sign for the curve ahead particularly in mountainous and steep terrain should always be accompanied with chevron signs at the outer edge of the curve and appropriate delineation.

The following guidance should be adopted while installing curve signs:

The curves with radii up to 450 m should be provided with curve warning sign in advance of hazard and single chevrons on outer edge of curve. Spacing of chevron signs should be such that the road user always has at least three signs in view, until the change in alignment eliminates the need for the sign as per IRC:67. Chevron signs should always be placed on outer edge of the curve and spaced uniformly for the length covering transition length and the straight portion as given in IRC:67 as per **Table 10.2**. On curve with radius less than 450 m, the safe negotiating speed for the curve should be placed along with curve warning sign at both approaches. Generally, if the difference between the approach speed and permissible negotiating speed of any curve is more than 15 km/h, the curve warning and speed limit sign should be placed on both sides. All signs should be installed on both approaches.

Table 10.2 Spacing of Single Chevron Signs

Curve Radius(m)	**Distance Between Chevron Sign Boards (m)**	
	On Curve	**Before Curve (on the transition length, if any)**
50	15	30
100	20	40
200	30	60
300	45	90
400	60	120
450	70	140
451-750	75	150
>750	80	160

a. The curves with radii 751 m to 1200 m with deflection angle greater than 20 degrees should be provided with single chevron signs on outer edge of curve at 80 m spacing.

b. Depending upon the sharpness of curve, single chevron, double chevron sign and triple chevron sign should be installed as detailed in **Section 10.8.3**. Delineators should be provided at all the curves as per IRC:79. Spacing of the same on horizontal curves as shown in **Table 10.3.** On straight sections, roadway indicators should be spaced uniformly 50 to 70 m from each other.

Table 10.3 Spacing of Delineators on Curves

Radius of Curve (meters)	Spacing on Curve (S) (meters)
30	6
50	8
100	12
200	20
300	25
400	30
500	35
600	38
700	42
800	45
900	48
1000	50

c. For curve treatment, delineators should be supplemented with chevron signs and the spacing of such delineators on curves should be in conformity with the radius of curve given in **Table 10.3**. A typical illustration of a curve treated with chevron signs and delineators is shown in **Fig. 10.1** under **Section 10.9.2** of this document.

10.18.3.1 Traffic Signs for Intersections

Gantry and shoulder mounted Advance Direction Sign should be provided in advance of a junction/ VUP or any urban reach. Stack type advance direction sign and flag type direction sign should be provided for at-grade junctions. Reassurance sign or Route confirmatory sign should also be given as per IRC:67 at spacing not greater than at every 10 km.

The junction control should be established either with “STOP” or “GIVEWAY” sign based on visibility funnel given in IRC:67 and IRC:35. The “STOP” and “GIVEWAY” sign should not be installed on major road, but, should always be on side road only (except for roundabout in which “GIVE WAY” sign should be given). For junction with substantial turning traffic, the roundabout or traffic signal should be used for controlling the traffic, for which, the signs mentioned in IRC:67 should be adopted. The tip of all splitter and triangular islands should be installed with the direction regulatory sign of appropriate size along with Object Hazard Markers. Though both signs can be installed in one post, the minimum clearance between vertical faces of signs and kerb as specified in IRC:67 should be ensured while installing them.

The approach arm to roundabout should be provided with GIVEWAY sign and central island with turn left sign and double chevron signs as given in IRC:67. Relatively insignificant minor road approaches should be provided with STOP sign and also rumble strips at 8 m to 12 m away from start of the curve on minor road, whereas a side road warning sign should be placed on major road.

10.18.3.2 Facility Information Signs

Roadside facility information sign should be provided wherever necessary such as near Eating places, Filling stations, Police stations and Hospitals.

10.18.3.3 Prohibitory Signs

Required prohibitory sign should be placed for prohibiting certain movements or activities such as No Overtaking, No Parking and No Standing in the hill road section.

10.18.3.4 Pedestrian and School-Zone Signs

Pedestrian guard rails should be provided to streamline them into safe zebra crossing locations. Pedestrian guard rail should be of forgiving type. The zebra crossing should be provided with warning and informatory signs. On approach to school zone, warning sign should be provided with school zone ahead and speed limit signs as per IRC:103. It is recommended to use type XI fluorescent yellow green retro reflective sheeting for this case as fluorescent sheeting have property of working better during dawn/ dusk and it also attracts attention of road users.

10.18.3.5 Toll or Fee Plaza Related Signs

Toll plaza related signs as per IRC:67 should be provided including the user fee notification boards.

10.18.3.6 Display of Road Safety related Slogans

Display of appropriate slogans at prominent locations along the road plays a significant role in maintaining due causation during journey, ensuring safety of road users, make the journey entertaining and break monotony. It is therefore necessary that appropriate slogans should be displayed along the road at prominent places. In this connection various slogans have been compiled and suggested here at **Appendix-10.1** for ready reference. The construction agency should accordingly use these at suitable location appropriate to that place and keep the road user, well informed, alert, and active during journey and make his journey pleasurable.

10.18.4 *Road Markings*

Road markings should be of hot applied thermoplastic materials with glass reflectorizing beads or with preformed adhesive retro reflective tapes and their design and specifications should be as per IRC:35. The quality of thermoplastic application should be ensured by testing actual samples by random selection during application time to avoid any possible deception in the quality of materials used. Road marking should meet the performance criteria for both day and night-time visibility with dry retro reflection and wet retro reflection as per IRC:35.

10.18.4.1 Longitudinal Markings

No overtaking zone markings should be marked as per IRC:35 when the sight distance available is less than the minimum visibility distance. The centre line should be either with single or double line and wherever enough space is available, it should be with hatch marking as given in IRC:35.

10.18.4.2 Diagonal and Chevron Markings

Chevron marking should be provided for all entry/ exit points and should be in continuation of shoulder edge line. Diagonal marking should be provided in case of opposite stream of traffic.

10.18.4.3 Bus and Truck Lane Marking

Bus and truck lane marking should be provided with adequate chevron marking and (Reflective Pavement Marker) RPM at diverging/ merging locations with main carriageway. The continuity of shoulder edge line should be maintained while making chevron markings.

10.18.4.4 Stop Line and Give Way Marking

Stop line and Give way marking should be provided for side road, which should also be in continuation of shoulder side edge line.

10.18.4.5 Pedestrian Crossing Marking

The pedestrian crossing in mid-block section should be provided with a platform on kerb so that pedestrians can wait comfortably without being directly exposed to motorized vehicular movement.

10.18.4.6 Hatch Marking and Ghost Islands

To avoid road crashes by hitting raised islands, hatch marking should be provided to confine the drivers within the required space. In a junction, where physical islands cannot be placed, wide open area effect can be avoided by providing ghost island so as to streamline the traffic movement.

10.18.4.7 Longitudinal Marking to Toll Booths

The traffic lane/ centre line/ edge line marking should be continued till the toll booth in such a way that traffic from each lane of the hill road is guided to discharge uniformly to different toll booths. Toll booth should be provided with chevron marking and hazard markers as per IRC:35. There should be transverse bar markings to alert the traffic about the approaching toll booth.

10.18.4.8 Parking Restriction Markings

In order to establish restriction marking, the edge line and kerb can be marked in yellow colour. Zig-zag yellow marking should also be applied in such location.

10.18.4.9 Object Markings

To streamline the traffic through the defined pathway and also to discourage zig-zag vehicular movements, the paved surface between edge line and the adjacent raised islands/ separators/ barriers should be provided with diagonal markings as per IRC:35.

10.18.4.10 *Speed Calming Measures*

At locations where vulnerable road users are exposed to high-speed vehicular movement, the speed can be physically curtailed by speed calming measures as per IRC:99. At locations where VRUs are exposed to vehicular traffic, the safe speed limit must be decided based on the human injury tolerance criteria as mentioned in **Para 10.16**.

10.18.5 *Road Delineators*

Road delineators such as roadway indicators, hazard markers and object markers should be installed as given in IRC:79.

10.18.5.1 Roadway Indicators/ Guide Poles

Ellipsoidal or circular mild steel posts or with thermoplastic body of 1.0 m height with white retro-reflective band of type XI sheeting as per criteria, placement and spacing given in IRC:79 should be provided. It may be placed either on the parapet or at the edge of the earthen shoulder depending on the available roadway width and Right of Way (RoW).

10.18.5.2 Median Marker

Median Marker should be used for improving median visibility during night time. Use of median marker reduces chances of collisions with medians during night time or severe weather. They should also be used to highlight the parapet walls of structures such as bridges and culverts. Median Marker should be provided with fluorescent yellow colour retro reflective sheeting type XI as per IRC:67.

10.18.5.3 Object Markers

Object Markers should be provided as specified in IRC:79. It should be of Aluminum backed flexible prismatic sheeting confirming to type VI of ASTM D 4956. Hazards such as trees, electric poles and other objects which are above Finished Road Level (FRL) that are falling within 3 m from the carriageway edge line should be painted with object markers. This is essential for the objects to which providing an Object Hazard Marker (Hazard Marker) is difficult. Object markers with chevron pattern should be provided in all the curves which should be applied to the retaining wall/ rock for better curve delineation.

10.18.5.4 Hazard Markers

Hazard Markers should be provided as given in IRC:67 and IRC:79. All physical objects projects above the FRL that are falling within 3 m from the carriageway edge line should be illuminated with Object Hazard Markers (OHM).

10.18.6 *Reflective Pavement Markers (Road Studs)*

The Reflective Pavement Maker (RPM), i.e., road studs should be provided to improve the visibility in night-time and wet weather conditions. These should be made of polycarbonate or ABS moulded body and reflective lenses should be moulded of Methyl Methacrylate confirming to ASTM D 788 or equivalent, capable of providing total internal reflection of the light entering the lens face and should support compressive strength of minimum 13635 kg tested in accordance to ASTM D 4280 with hard abrasion-resistant lens surface. The reflective area should be 13 sq.

cm on each side and the slope to the base should be 35±5 degrees. It is recommended to use category a studs on hill roads. The manufacturer should mandatorily submit an independent laboratory test certificate of having tested the raised pavement marker lens for visual observations and coefficient of luminous intensity as per IRC:35, IRC:SP:91 and MORTH specifications.

Considering the frequency of the sharp curves and the visibility issues, the spacing of road studs should be followed as given in **Table 10.4.**

Table 10.4 Spacing of Road Studs

Radius of Curve (meters)	Spacing of Road Studs (meters)
Up to 30	2
31-150	3
>150	As per IRC: 35

10.18.7 *Solar Studs*

Solar powered road markers are more effective which can immediately draw the attention of drivers and should be provided at locations such as approach to road crash prone locations and highly hazardous locations (for e.g., bridges, toll plazas, sharp curves, pedestrian crossings, lane transitions, speed humps, junctions, channelizes, construction sites, rail road crossings, accident prone locations, median openings and lane changing locations) where performance of normal road studs are not that effective due to street lightings and other roadside activities.

As the name signifies, the solar road studs function automatically and obviously, they do not rely on vehicle head light. The intense brightness of the Light Emitting Diode (LEDs) makes them visible at distances of more than 800m under favourable conditions. Also, the solar studs are more distinctly visible during rainy and foggy conditions where the road markings could be ineffective.

At locations where solar studs are intended to be used, the spacing should be the same as indicated for conventional road studs. Wherever solar studs are to be installed, it must be ensured that sufficient sunlight is available.

10.19 Recommendations

Keeping the various safety aspects of the road users of hill roads in view, the safety scenario can be improved by the following measures listed below in combinations:

a.) Providing geometric standards of roads as per specifications

b.) Road safety audit at various stages and incorporating its recommendations

c.) Placement of relevant traffic control devices including proper road signs (warning, cautionary and mandatory sign), road markings, road delineators and road studs should be done properly

d.) Regular maintenance of the road

e.) Adequate drainage system

f.) Construction of protective structure for traffic such as parapets, railings, snow sheds, boulder net, etc.

g.) Enforcement of traffic discipline, traffic rules/regulations

h.) Road Safety Audit at pre-opening/ O&M stage (post construction) of hill road should be conducted on regular intervals (minimum once in a year); however, the frequency can be reduced depending on traffic and road condition

i.) Identification of black spots and prompt rectification

The efforts should be directed at ensuring safe and comfortable travel at design speed for the road user in hilly regions.

11. TRAFFIC MANAGEMENT

11.1 General

In hill roads, the traffic diversion plan during construction shall be prepared conforming to IRC:SP:55. There are several typical situations in which traffic management becomes essential. Traffic management can be classified into two categories:

- One which requires traffic management due to closure, mishaps, etc.
- The second, where traffic is required to be regulated to improve operation and safety.

The following belongs to first category:

a) Closure due to landslide, snowfall, blizzard, road crashes, etc.

b) Protection of places of road repair

c) Operation of certain section as one-way lanes

d) Weather warning

The second category comprises the following:

a) Speed restrictions

b) Restriction on parking

c) Use of relevant traffic control devices including relevant road signs like speed limit signs, curve warning signs, central line marking, no overtaking zone sing, pedestrian cross walk, warning about land slide/ rock fall areas and relevant road markings, etc.

d) Lane restrictions, time restrictions or gate system for Up and Down traffic, wherever required.

11.2 Arrangement when Traffic is suspended

In the event of traffic being suspended on a section of hill road, the following traffic arrangement should be made:

a) If the duration of suspension is such as to necessitate diversion of traffic to another route, guidelines about this should be provided at the appropriate location on either side of the damaged section, where it would be possible for the through traffic to alter its course. It should be done with the help of suitable warning signs put up in a pair, one just close to intersection affected location and the other one at 30 to 60 meters away depending on vehicle speeds at the site. In addition, a prominent "ROAD CLOSED" sign should be fixed on the far side of the intersection blocking half the width of carriageway. Word message on the signs may be in more than one language according to needs of the road users. To regulate traffic at the points of re-routing, police help may also be requisitioned. Together with this, press and other mass media should be used to notify the public about road closure and alternative routing for the through traffic. A typical information board may be as under:

When road is closed:

i. ----------- Road is closed at KM-------------- at ------------------hrs. on ------------------------due to ---------- to be opened on -------------

When road is opened:

ii. ---------------Road at KM---------- since opened for traffic.

b) Similar sign boards should be erected at the junction where the traffic is to take a diverted route requesting to follow diversion. Alternate solution for (a) and (b). Portable Variable Message Sign (VMS) with Road Open and Closed Information.

c) Strong inviolable barriers should be erected in the immediate vicinity of the damaged section on both sides so that traffic can have no chance of going through imprudently. Besides, regulatory signs announcing that the road ahead is closed should be installed on the approaches; one sign at 10 m from the barrier and the other at 30 to 60 m further away.

d) The barricades should be protected by solar blinker with red beacon or better visibility in the night. In addition, alternate object markers with black and yellow diagonal strips (Aluminum flexible prismatic sheet) with retro reflectorized sheets Type VI shall be used on these barricades for effective advance warning.

e) The construction traffic may be allowed through a small opening (about 3 m wide) at the extreme edge of the roadway, normally kept blocked with a double row of painted plastic drums or barrier conforming to IRC: 55 which shall only permit the construction vehicles to pass.

f) Signs, lights, barriers and other traffic control devices should be kept maintained in a satisfactory condition till the time the traffic is restored and allowed to follow its normal path.

g) Typical traffic management plan shall be prepared for each location to ensure adequate visibility and sight distance on curve, etc.

h) All the channelizing devices shall be retro reflectorized using flexible and re-boundable retro reflective sheeting of Type IV grade that meets the required parameter as per ASTM D 4956 Clause S2.

11.3 Arrangement when part of Carriageway is blocked and leading to One Way Operation

Blockage of part carriageway on account of landslides or repair/construction of cross-drainage works is a common occurrence in hill roads. In such cases, the following general guidelines should be kept in mind:

a) Traffic may be passed either over part width of the structure or a temporary diversion, depending on site conditions, intensity and volume of traffic, preferably on economic considerations and other related matters. The former method should be employed as far as possible especially when the work could be conveniently carried out in half width at a time and there are no undue problems in channeling the traffic through the available road width, also keeping in view the safety of the construction workers. In both cases, the work should be planned such that widening/reconstruction of the cross-drainage facility is over in the shortest time possible following properly conceived construction schedules. Such timely construction schedule is possible only if all the materials and other equipment are collected at site in advance before the work commences.

b) One-way traffic operation should be established whenever the traffic is to be allowed over part width of structure. This should be done with the help of flagmen, positioned on opposite sides, who should be on duty during all hours. For regulation of traffic, the flagman should be equipped with red/ green flags and blinking LED Lights or reversible stop/ go sign board. Wherever possible, short-range radio transmitters may be used for communications if blocked stretch is long.

c) If for any reason traffic cannot be allowed over part width of a structure, a temporary diversion should be constructed. The width and paving specifications for diversion should be decided on factors like period for which diversion will be in use, intensity and volume of traffic and climatic conditions. Attention must also be given to the avoidance of dust nuisance. On both ends, the diversion should be joined to the main carriageway with smooth transition, with visibility requirements fully taken care of.

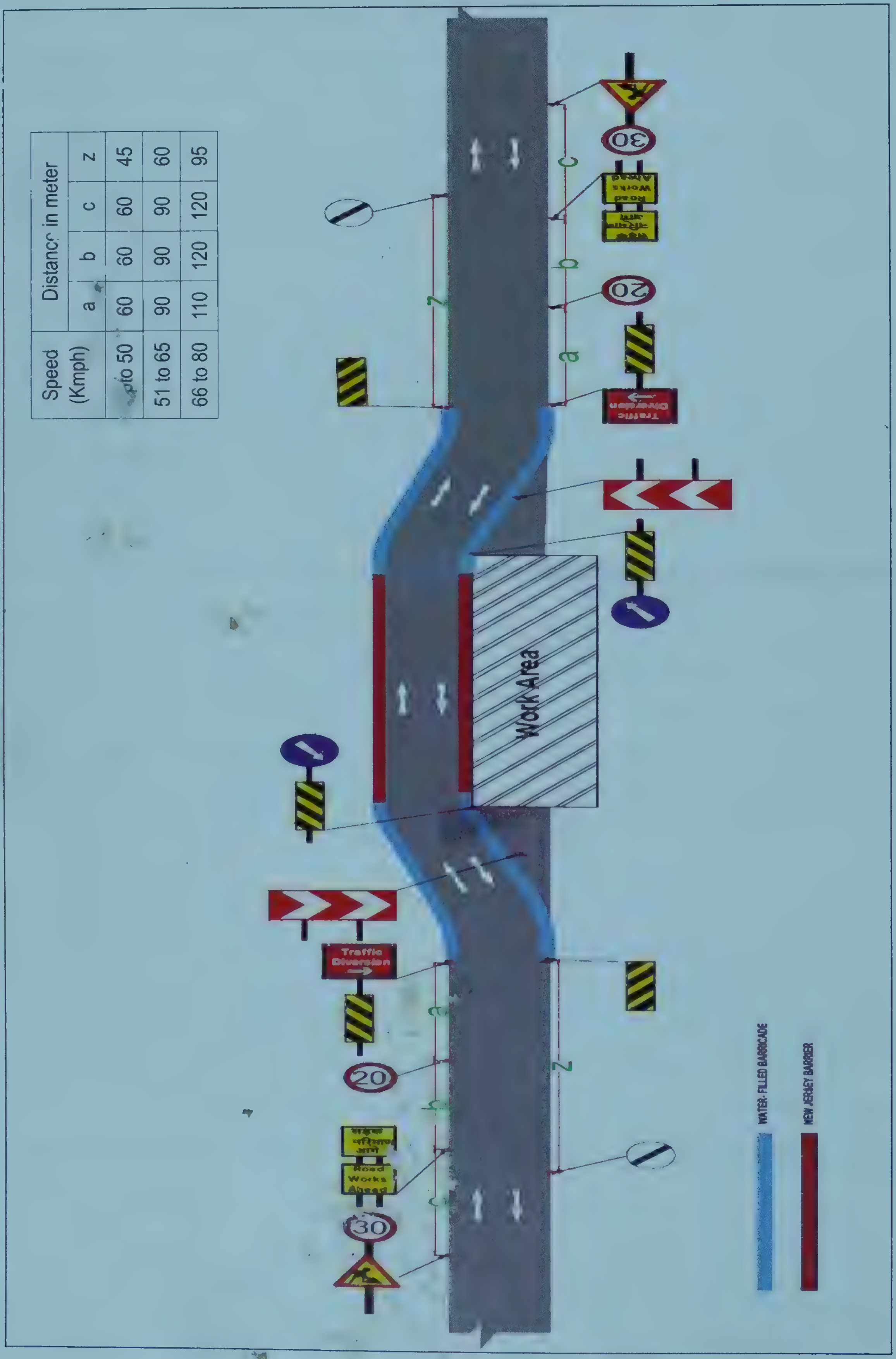
d) At the point where traffic is to be deviated from its normal path (whether on temporary diversion or part of the carriageway), the channel for traffic should be clearly marked with the aid of pavement marking coupled with erection of plastic drum pasted with Type IV re-boundable retro-reflective sheeting to enhance the night visibility. At night, the passage should be delineated with solar LED lights or suitable light source.

e) Strong barriers of suitable design should be erected on either side of the portion of carriageway closed to traffic, both when the traffic is to be turned to a diversion road or channeled on to part width of the structure. For protection of traffic, red LED light or solar blinking light and retro reflective hazard marking sheeting shall be mounted on the barriers. Besides, barricades shall be treated with alternate black and yellow or white and red retro-reflective sheeting confirming to Type IV grade as per ASTMD 4956 to improve its night visibility.

f) On both sides, suitable regulatory/warning signs as per IRC:67 should be installed for the guidance of road users. Word message on the signs may be in more than one language as necessary. On each approach at least two signs should be put-up, one close to the point where transition of carriageway begins and the other one at 60-120 m away and can be varied as per site conditions. As shown in **Fig. 11.1**, the signs may be placed in the following order: “PEOPLE AT WORK” sign followed by, “NARROW ROAD AHEAD” sign, followed by “KEEP LEFT” sign at the start of work area and followed by “RESTRICTION ENDS” sign after the work zone.

g) Sign, lights, barriers and other traffic control devices, as well as the temporary diversion should be kept well-mentioned till such time the traffic is again able to follow its normal path.

Typical arrangement for the case when traffic may be passed over part width of a structure is shown in **Fig. 11.2**


Work Area
Traffic Diversion
Road Works Ahead
30
20
a
b
c
z
WATER- FILLED BARRICADE
NEW JERSEY BARRIER

Speed (Kmph)	Distance in meter			
	a	b	c	z
[illegible] to 50	60	60	60	45
51 to 65	90	90	90	60
66 to 80	110	120	120	95

Fig. 11.1 Arrangement for Traffic Diversion

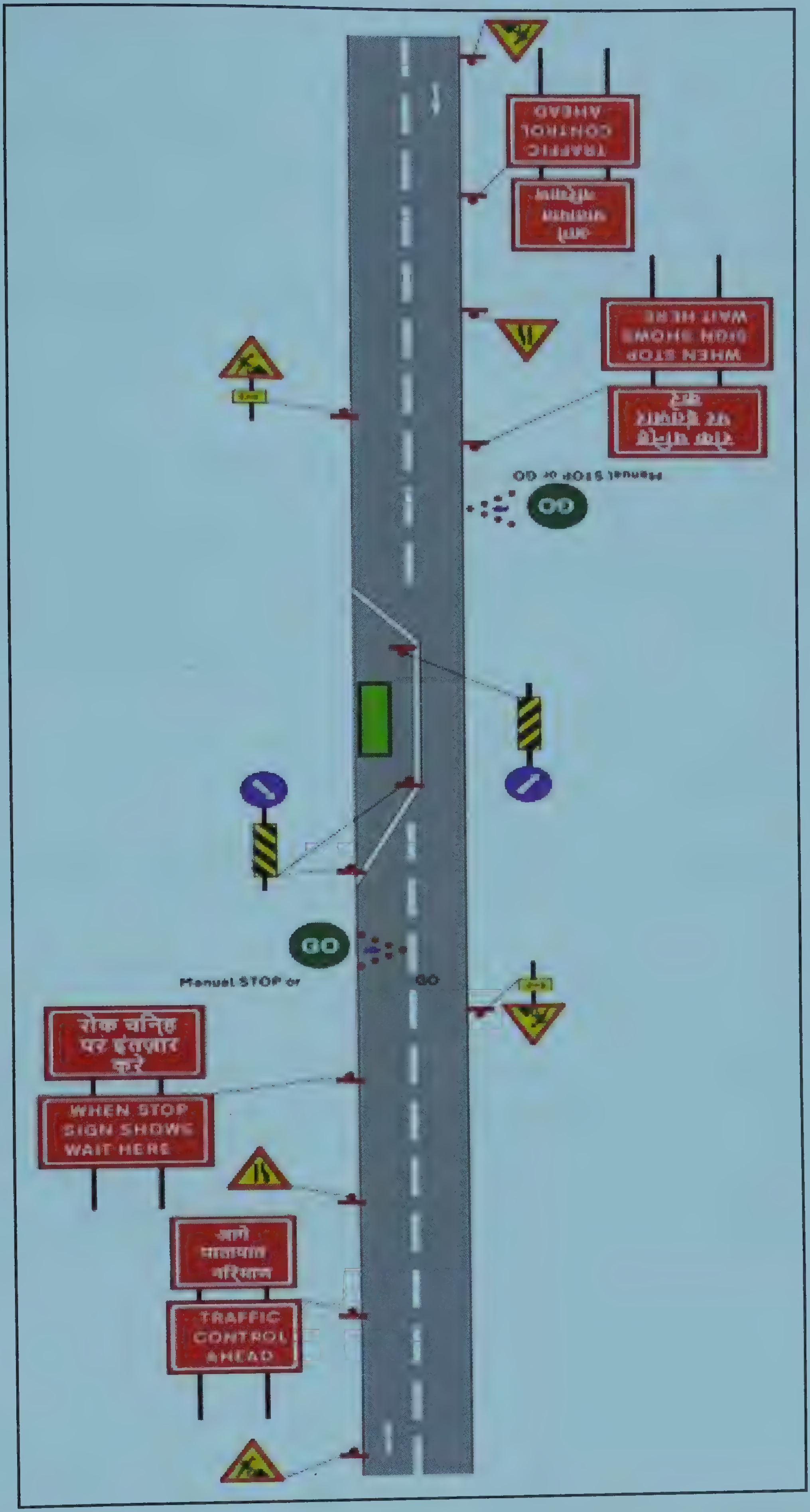

TRAFFIC CONTROL AHEAD
WHEN STOP SIGN SHOWS WAIT HERE
Manual STOP or GO
GO
GO
Manual STOP or GO
रोक चिन्ह पर इंतज़ार करें
WHEN STOP SIGN SHOWS WAIT HERE
TRAFFIC CONTROL AHEAD

Fig. 11.2 Arrangement during Reconstruction of Cross Drainage Structures where Traffic can be passed over part width of structure

11.4 Large Signs for Weather Warning

At the start of sections subject to closure under bad weather conditions and at other frequently travelled sections, large VMS conforming to IRC:SP:85 and IRC:SP:110 should be installed to provide warning and/or information to users of conditions expected on the route. The sign should also be used to inform public of the section which are closed due to blizzard, landslides, etc.

11.5 Other Traffic Signs and Marking

An essential element of traffic management in hill roads is existence of proper traffic signage and marking conforming to IRC:SP:55. In general, to be effective, the sign/ markings should only be installed wherever needed, they should convey a clear simple warning, and command respect and attention of road user and give adequate time for proper response. It is, therefore, very important not to allow unauthorized and unnecessary sign on roads. As fog is a problem in many such roads so use of Type XI Fluorescent yellow retro reflective sheeting as a backing board shall be recommended for sign boards.

11.5.1 *Speed Limit Signs*

In hill roads, speed regulations and speed limit are necessary to supplement motorist's judgment in determining speed that is reasonable and proper for weather and roadway conditions. Speed limit should be imposed to reduce accidents and improve traffic flow. However, if the speed limit are unreasonable, the limit will be disobeyed and loose much of its value. The speed limit signs should conforming to IRC:67. The speed limit should be determined based on where applicable proper engineering and traffic data, i.e., prevailing wind speed, physical features of road, crash experience, traffic characteristics and traffic control.

11.5.2 *Curve Warning Signs*

On sharp curves, i.e., curves that permit less than the general operating speed of the highways, curve sign shall be provided and advisory speed plate shall be added below it. Chevron sign shall also be provided as per IRC:67.

11.5.3 *No Parking and No Standing/Stopping signs*

Safety, comfort and convenience of road users, demands a proper and effective regulations of parking on hill roads, due to inadequacy of wide areas for parking on roadside and steep slopes. Parking restriction should be placed after a careful study of traffic patterns and engineering requirements. The signs for controlling parking should confirm to IRC:67 "Code of Practice for Road Signs" and should be accompanied by suitable kerb or carriageway marking as indicated in IRC: 35.

11.5.4 *Centre Line and No Passing Marking/Signs*

In accident prone location and sharp curves where head-on collision are common, central line marking should be provided as indicated in IRC:35. On curves with radius less than 150 m, the road carriage way width shall not be less than standard two lane width and center line of the carriage shall be marked by road studs/ cat's eye. The spacing of road studs shall be as per **Table 10.4 (Para 10)**.

11.5.4.1 No-passing sign and painting of strips as per IRC:35 mentioned in preceding paragraphs, should be adopted where the passing sight distance is restricted, and volume of traffic is high.

11.5.4.2 Other useful signs for regulating traffic on hill roads which are given in IRC:67 and shall be used at locations like "FALLING ROCKS", "LOOSE GRAVEL","STEEP ASCENT", "STEEP DESCENT","NARROW BRIDGE",NARROW ROAD AHEAD"," ROAD WIDENS

AHEAD", "DANGEROUS DEEP" , "HUMP", "HAIRPIN BEND", "REVERSE BEND", "CURVE, "CUMPULSORY SOUND HORNS","SLIPPERY ROAD" etc.

11.6 Traffic Regulation in Winter

To reduce the incidence of road crashes with ice and snow bound area, the following measures are recommended:

a) Provide information to the road users in advance to reduce the elements of surprise as far as possible by providing VMS strategically prior to alternative cross route.

b) Impose lower speed limits.

c) Surveillance of traffic and road conditions through Pan Tilt Zoom (PTZ) camera at the vulnerable location connected with Optical Fiber Cable (OFC) and electrical power.

11.7 Weather Information System

11.7.1 On important roads especially in snow bond areas, it is essential to develop a "Road weather information system" which should contain several field stations and a central unit. Field stations should be equipped with sensors to determine the temperature of road surface, humidity, wind speed and its direction, condition of road surface (wet, dry, slippery) and information about weather (precipitation).

Inclement weather is hazardous on hill roads and more so in high altitudes. The change of weather can occur faster and sudden. Sensitive barometer may be utilized to forecast change likely in weather. Drop in pressure indicates approaching inclement weather. The siting of field station should be preceded by detailed climate survey to ensure best possible sites.

11.7.2 The field stations should be linked to central station by OFC network and electrical connection in addition to satellite, telephone and/or radio control sets. The central unit should be equipped with computer to record and analyze the data and a communication system to transmit data and warnings to public and field maintenance units through VMS as per IRC:SP:85. Road user can see the information on VMS installed before start of such sections of hills or restaurants/ eating places along the routes. Road users can also be informed over the radio and other mass communication system. Access to weather information system should be available online in order to aid planning of journey across such critical areas.

11.8 Advance Traffic Management System (ATMS)

Provision of VMS as per IRC:SP:85 at strategic locations at least 3 pairs, PTZ camera at strategic and vulnerable location at least at every 5 kms connected with OFC to screen of at least 16 modules (overall size 8mx 2m) in Control room having area of minimum 125 sqm should be made. A Hall, two rooms and toilet facilities at First floor / Level 2 should be included in Toll Plaza
.

12. ROCK BLASTING

12.1 General

Blasting of rock disturbs the stability of nearby hill side to a great extent. This also results in landslides and slip zones causing considerable damage to property. For road construction in hills, rock blasting may be inescapable but it should be done in a methodical manner so as to cause minimum disturbance to surrounding mass. There should not be tendency to resort to excessive rock blasting only for immediate economy in cost and expediency of construction work. Rock blasting preferably should be done for hard rocks and also where road cutting cannot be done manually by shovels, crow-bars, rock breakers and excavators. For restricting rock blasting to the barest minimum the following guidelines must be strictly followed.

12.2 Guidelines

12.2.1 All the staff involved in rock blasting work, right from the Engineer to the skilled worker must be given necessary training and consciousness regarding grave adverse ecological effects as well as danger to life and property due to rock blasting so that they do rock blasting only when unavoidable and do it in the proper manner consciously. The manufacturers of explosives normally arrange training courses for users on request and many premier institutes also run courses which should be subscribed to.

12.2.2 Rock blasting must be properly planned and controlled. Rock blasting work for a project must be planned in detail at the stage of preparation of estimates. The blasting work must be carried out under the direct supervision of a Junior Engineer or trained Supervisor. Daily account must be maintained of rock blasting to be done, explosives planned/expected to be used and actually used under the direct control of the Engineer and wherever there is 'any anticipated deviation in quantities from that planned it should be checked. Only just sufficient quantity of explosive should be issued in the morning for the days work and consumption justification should be scrutinized at the close of day's work.

12.2.3 For blasting, holes should be drilled based on a deliberate pattern to ensure free face and minimized explosive damage zone in to the parent rock. In case of large scale blasting to be done by electric detonators, delay detonators should be used in order to economize on explosive content and disperse shock waves.

12.2.4 On hill roads-blasted material and debris rolling down should be avoided where these are likely to result in adverse environmental impact, destabilization of hillside or cause soil erosion. The debris should be moved to designated muck disposal points which should be properly designed and stabilized.

12.3 Necessity of Rock Blasting

Since hilly regions in the country have predominance of rock varieties in some areas, blasting is rather a necessity in road construction activities. Blasting is required for rock excavation in hill sides, through cutting and quarrying. Blasting of ledge or half tunnel across a cliff face may also, sometimes, be necessary. Before deciding the exact alignment of the road and method of cutting, the dip/strike of the rock must be carefully examined to ensure that the completed road would be stable. Particular care should be taken to detect faults, which often provide planes of potential slips which may be dangerous.

12.4 Explosives and Accessories

12.4.1 The choice of explosives and accessories depends upon the nature of strata and its characteristics.

12.4.2 An explosive is a substance or a mixture of substances, which for the purpose of transport, handling and storage is in stable equilibrium. The equilibrium is upset, if subjected to severe shock resulting in violent release of energy in the form of shock wave accompanied by extremely rapid conversion of the explosives into a large volume of gases at high temperature and pressure. The necessary shock is provided by means of a detonator or detonating fuse. The explosives are normally Nitroglycerine based, though Ammonium Nitrate based explosives are also available. For road construction, nitroglycerine based gelatin is used. These are known by trade/brand names and terms 'gelatine" or "special gelatine" of various strengths or power are commonly used.

12.4.3 *Properties of Explosives*

(i) Power

The most important property of an explosive is its strength or power. Blasting gelatine, the most powerful of all commercial explosives, is taken as the standard and the power of all other explosives are measured in relation to the power of blasting gelatine, indicated as percentages.

(ii) Velocity of Detonation

Detonation of an explosive is the rate which the detonating wave travels through a column of explosives and is of considerable importance since shock energy of detonation increases rapidly with velocity. High velocity explosives are preferred for special purposes such as plaster shooting and underwater work. Low velocity explosives are most suitable where excessive shattering is to be avoided.

(iii) Density

The density is important when selecting an explosive for a particular use. With a high density explosive the energy of the shot is concentrated, a desirable feature in tunnelling whereas a low density explosive distributes energy along the shot hole.

(iv) Water resistance

Explosives differ widely in resistance to water and moisture penetration. While some explosives deteriorate rapidly under wet conditions, others are designed to withstand water for considerable periods. If blasting is to be done under wet conditions, a water resistant explosive should preferably be selected.

(v) Sensitivity

An explosive must not be sensitive to normal handling, shock and fraction, but it must remain sufficiently sensitive to be satisfactorily detonated and capable of propagating satisfactorily, cartridge to cartridge even over short gaps, such as may occur in practice.

(vi) Fume Characteristics

Explosives when used under stipulated ventilation conditions should liberate minimum of harmful gases in the process of detonation.

(vii) Thermal Stability

Explosive combination should be such as to be stable under all normal conditions of transportation, handling and usage. This is extremely important as use of explosive itself depends on this characteristic.

12.4.4 *Explosives in Common Use*

(i) The details of some explosives most commonly used in road construction are given in **Table 12.1.**

Table 12.1 Explosives in Common Use

Name of Explosives	Velocity of Detonation (confined) metres/sec	Normal Density gms/cc	Nature of Rock to be Blasted
Blasting gelatine 90%	5000	1.40	Quartzite, very hard granite
Blasting gelatine 80%	5000	1.40	Hard rock formation
Blasting gelatine 60%	5000	1.40	Medium, hard and soft rock
Slurry explosive 80%	3400-4000	1.15 to 1.25	Hard rock formation

(ii) The explosives are supplied in cylindrical cartridges of diameter varying from 25-32 mm and length 200-250 mm, the weight of a cartridge being 130-220 gm depending on size.

12.4.5 *Detonator*

(i) High explosives are by themselves not very sensitive and need some form of intense local shock to initiate them. This shock is produced by a detonator. Extremely sensitive composition are loaded in small quantities into copper or aluminium tubes to form detonators and in this form, they are used to prime charges on high explosives. It is the spark SPIT from a safety fuse, which causes the detonator to explode. A variety of detonators are used for blasting.

(ii) Plain Detonators

Plain detonator for use with safety fuse, consists of a small aluminium tube closed at one end. It contain a base charge of PETN (PENTA ERYTHRTOL TETRANITRATE) and a priming charge of ASA composition (lead azide, lead styphnate and aluminium powder) in an aluminum tube. This standard tube is known as a No. 6 detonator and is commonly used. Super plain detonators No. 8 strength are also used for specific purposes.

(iii) Ordinary Electric Detonators

An ordinary or instantaneous electric detonator is essentially a plain detonator plus a fuse head coupled to a pair of leading wires and is triggered by electric current.

(iv) Delay Detonators

Many blasting operations call for a series of shots to be fired in a pre-determined sequence, which can be achieved by the use of short delay denoters. This detonator consists basically of an electric detonator with appropriate delay element interposed between the fuse head and the priming charge. There are eleven detonators in this range, numbered 0 to 10 (the number of delay detonators of certain manufacturers has been increased to 16, numbered 0 - 15) with nominal delay intervals of 25 milli seconds (increased in later numbers) between consecutive numbers having leading wires of 24 SWG, PVC coated.

(v) Sketch of various types of detonators and fuse head is given in **Fig. 12.1.**

12.4.6 *Detonating Fuse*

Detonating fuse is a simple and safe device for initiating cap sensitive commercial explosives particularly suitable for simultaneous firing of multiple charges and for the mass initiation of large charges. It consists of a core of PETN with covering of textile and plastic. It is initiated by a No. 6 detonator and detonates at a velocity of approximately 6500 m/sec.

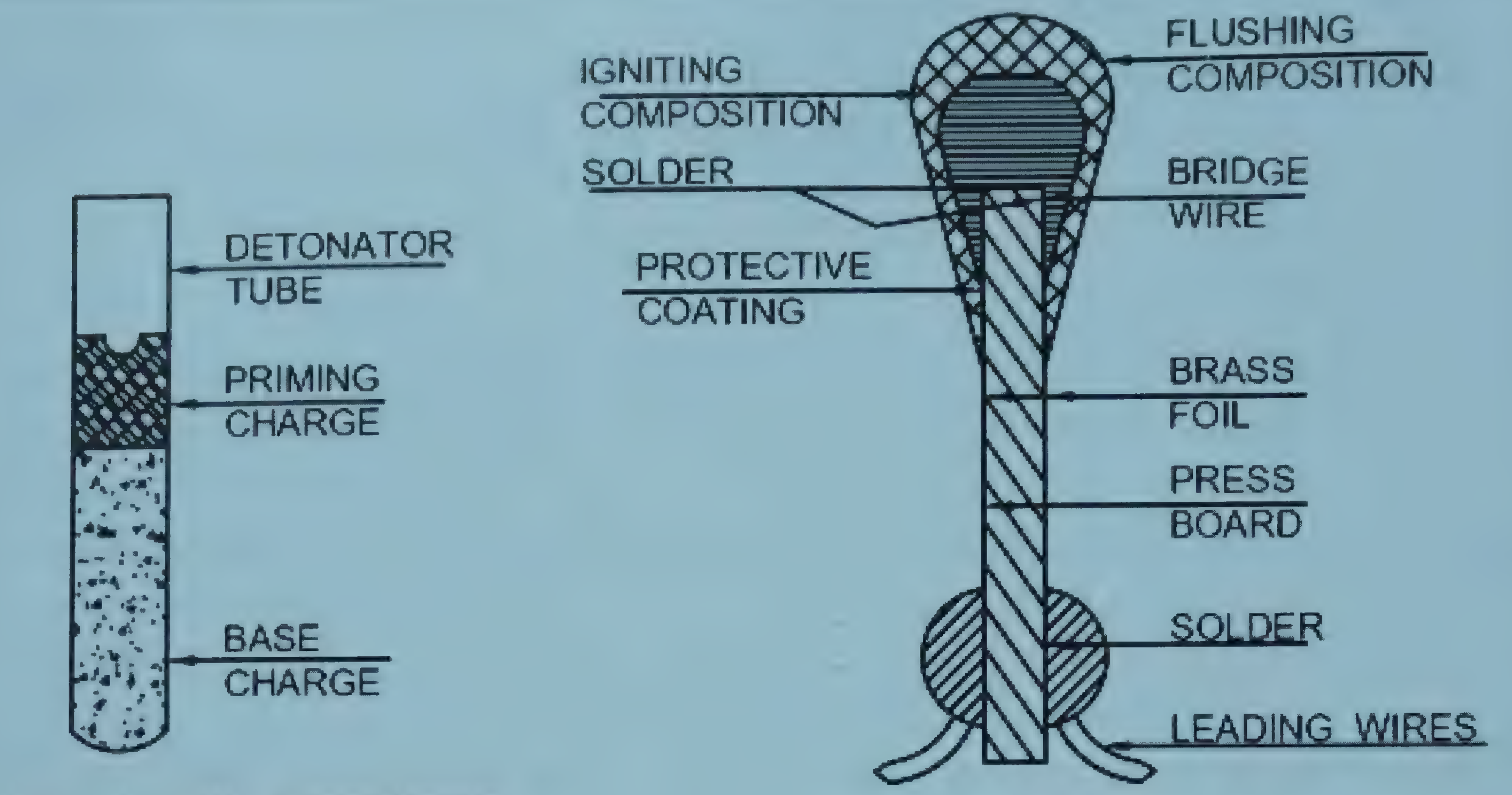

DETONATOR TUBE
PRIMING CHARGE
BASE CHARGE
IGNITING COMPOSITION
SOLDER
PROTECTIVE COATING
FLUSHING COMPOSITION
BRIDGE WIRE
BRASS FOIL
PRESS BOARD
SOLDER
LEADING WIRES

FIG. (a) PLAIN DETONATOR

FIG. (b) ELECTRIC FUSE HEAD

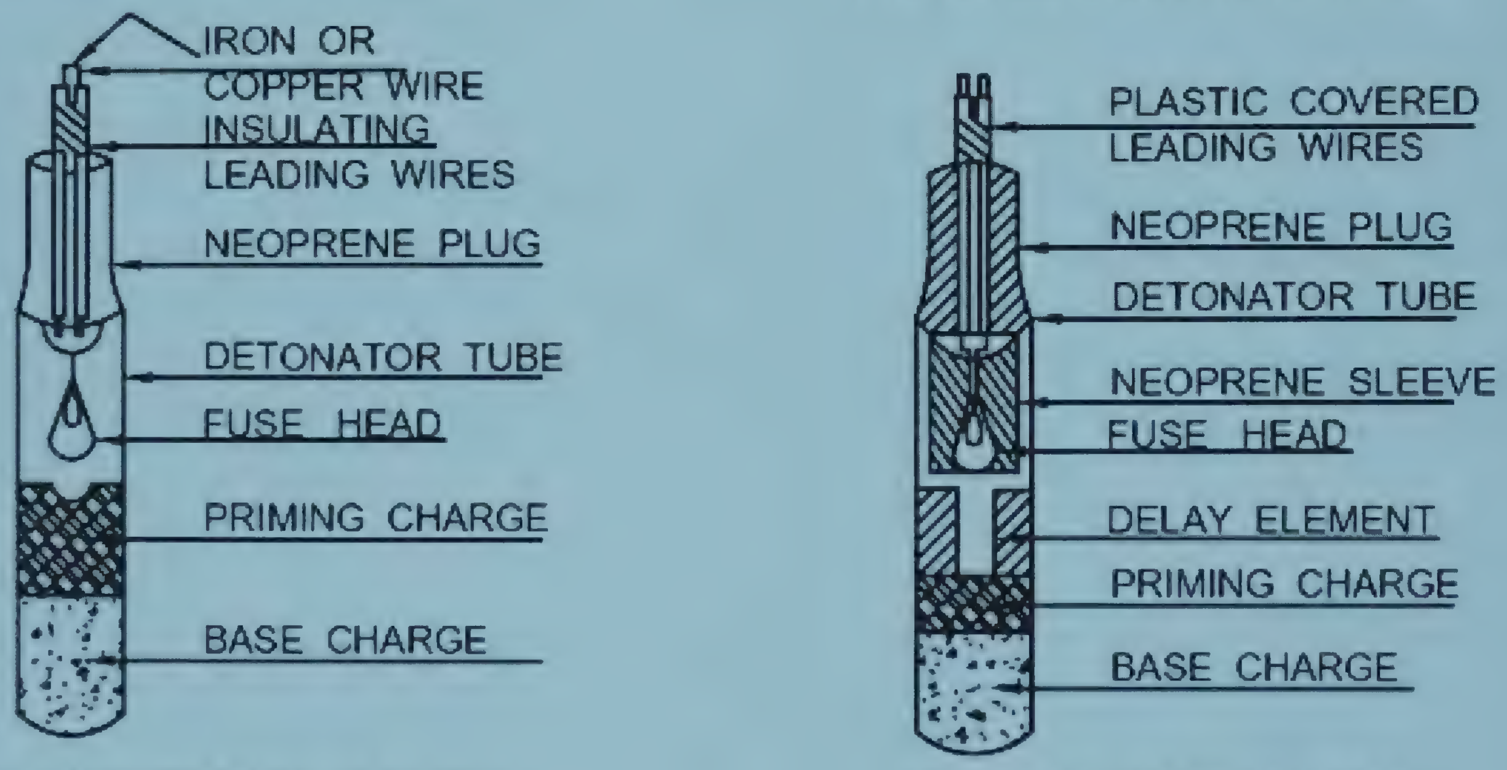

IRON OR COPPER WIRE
INSULATING LEADING WIRES
NEOPRENE PLUG
DETONATOR TUBE
FUSE HEAD
PRIMING CHARGE
BASE CHARGE
PLASTIC COVERED LEADING WIRES
NEOPRENE PLUG
DETONATOR TUBE
NEOPRENE SLEEVE
FUSE HEAD
DELAY ELEMENT
PRIMING CHARGE
BASE CHARGE

FIG. (c) SECTIONED ELECTRIC DETONATOR

FIG. (d) SECTIONED DELAY DETONATOR

Fig. 12.1 Detonators

12.4.7 *Safety Fuse*

Safety Fuse consists of a thin core of specially prepared black powder wrapped in layers of textile yarn and waterproof coating. The burning speed of safety fuse is controlled and is 100 to 120 seconds per metre.

12.4.8 *Exploder*

When explosives are to be initiated electrically a portable exploder for generating electricity is used. The exploders being manufactured in the country, have a range of 50 shots to 200 shots at a time. An exploder, is generally built on a metal chassis contained in a waterproof 'bakelite' case. It comprises of a dynamo which is operated by turning a handle. The A.C. Voltage generated by the dynamo is stepped up by a transformer rectifier and used to charge a condenser to a potential of not less than 1,200 volts. When the firing button is pressed the condenser is discharged through the electric circuit firing the shots.

12.5 Transportation of Explosives

12.5.1 *Rules and Regulations*

All the relevant central, state and local laws and rules and regulations framed thereunder shall be complied. Loading, unloading and handling of explosives shall be supervised by qualified personnel. At the time of loading or unloading of explosives, no electrical switch should be operated.

12.5.2 *Containers*

For carrying small quantity (upto 5 kg of explosives) specially designed insulated containers may be used. These containers shall be constructed of finished wood not less than 50 mm thick or plastic material not less than 6 mm thick or pressed fibre not less than 10 mm thick. Metal components, including nails, bolts, screws, etc., shall not be used in the construction of the containers, which shall be waterproof and provided with lids. The containers shall be provided with suitable non-conductive carrying device, such as rubber, leather or canvas handle or strap.

12.5.3 *Vehicles*

The vehicles used for transporting explosive shall be driven only by an experienced driver who is physically fit and is familiar with the precautions to be taken while carrying the explosives in his vehicle. All vehicles used for transporting explosives shall be maintained in good working condition and all systems of same must be checked before starting move of vehicle. The vehicles should preferably be enclosed type with locking arrangements and body-work leak-proof.

(i) In open body vehicle the floor of the vehicle carrying explosive shall be leak proof. The sides and ends shall be of sufficient height to prevent the explosive from falling off the vehicles.

    (a) The interior of the body shall not have any exposed metal parts, except those of copper, brass and other non-sparking metals and shall preferably be lined with wood.

    (b) The chassis of the vehicles shall be well sprung. The tyre pressure shall be maintained as per the requirement of the Indian Explosives Regulations.

(ii) All electrical wiring and equipment of vehicles shall be adequately insulated and protected against mechanical damage to prevent short circuiting.

(iii) Two carbon dioxide fire extinguishers, each of not less than 3 kg capacity, conforming to IS:2878-1986, shall be carried on each vehicle. The extinguishers shall be securely mounted on the vehicles in such a manner that they can be readily removed for use in an emergency.

(iv) A motor vehicle carrying explosives shall not be refuelled except in emergencies and even then only when the motor has been stopped and other precautions have been taken to prevent accidents.

(v) The quantity carried, in any single vehicle should not exceed 75% of its rated capacity or 3600 kgs, whichever is less.

12.5.4 *Safety Precautions in Transportation*

Safety precautions outlined below shall be observed for transportation of explosives.

(i) No metals except approved metal truck bodies shall be allowed to come in contact with cases of explosives. Metal, flammable or corrosive substances shall not be transported with explosives. As far as possible, transportation of any other material alongwith explosives shall be prohibited.

(ii) Smoking shall be prohibited in the vehicle carrying explosives and in its vicinity upto a distance of 30 m.

(iii) No unauthorized person shall be allowed in the vehicle carrying explosives.

(iv) Explosives and detonators of blasting caps shall not be permitted to be transported in the same vehicle.

(v) Detonators and other explosives for blasting shall be transported to the site of work in the original containers or in securely locked separate non-metallic container and shall not be carried loose or mixed with other materials.

(vi) Care shall be taken while loading and unloading of explosives, like inside of vehicle body must be free from grit, oil rags etc., unloading should not be done near exhaust of pipe, explosive protected from rain/prolonged exposure to sun, engine of vehicle switched off and no refueling permitted while unloading etc. The filled containers shall not be handled roughly or dropped.

(vii) Drivers shall not leave the vehicles unattended while transporting explosives.

(viii) The speed of the vehicle shall not exceed 25 km/h on rough roads and 40 km/h elsewhere.

(ix) Vehicles, transporting explosives shall not be taken into a garage, repair shop of-parked in congested areas, public parking or similar places.

(x) Explosives shall not be transported in trailers. Further, any trailer shall not be attached to a motor truck or vehicle when it is being used in transporting explosives.

(xi) Explosives shall not be transported on public highways during darkness, except in emergencies and even then only when the approval of the concerned authorities has been obtained. Such vehicles shall be fitted with adequate warning lights on both ends, while operating in darkness.

(xii) Explosives shall not be transferred from one vehicle to another on public highways, except in cases of emergency.

(xiii) When explosives are carried in a convoy, the distance between any two vehicles will not be less than 75 metres.

12.6 Storage of Explosives

12.6.1 Storage of explosives is regulated by Indian Explosives Act 1884 as amended from time to time and provision there under should be strictly observed, unless exempted under section 14 of the Act.

12.6.2 Explosives shall be stored only in a magazine, which is clean, dry, well ventilated, well illuminated where electricity is available, reasonably cool, correctly located (more than 100 mtrs from living accommodation) and protected against lightening if explosive is one ton or more in accordance with Indian Electricity Act and Indian Explosives Act. The magazine should be located on well drained sloping ground and away from built-up area/highway but approachable with all-weather road. In case of new storage accommodation for explosive, the local Inspector of explosive or other licensing authority should be consulted and care should be taken to ensure that the statutory distances from other buildings and property are observed.

12.6.3 All major dumps as well as dumps in disturbed area having explosive of 3 ton or more should be fenced with double fencing of barbed wire. Similarly all precautions of security must also be taken for safe storage of explosives.

12.6.4 Explosive cases should not be stacked in more than five tiers and should be stacked in such a way that ends of the cases showing the date of manufacture are visible, which will facilitate use of stock early.

12.6.5 Explosives upto 4 kgs should be kept in a securely locked container away from fire and detonators/capped fuses should be kept in separate containers. While storing explosive upto 20 kgs a small store/magazine should be built. In case of storage for large quantity, following guidelines be followed.

(i) Building should be specially constructed for this purpose situated away from residential/industrial area and highway.

(ii) About 2.42 sqm floor area should be considered for each ton of explosive. While stacking cases, each stack should not have more than 5 tiers and a working space of 1.22 m must be left between two stacks.

(iii) Where quantity of explosive exceeds 20 tonne a separate building for storage of detonators must be built and for leser quantity detonators can be stored in an annexe, which is built as integral part of main building but has a substantial partition with an air space between them. As a rough guide a double partition of 2 cm each with 45 cm air space between them will suffice the purpose of storing 10,000 detonators.

12.6.6 Blasting caps, electric blasting caps or primers shall not be stored in the same box or room with other explosives in big dumps. However, in small dumps sand bag revetments of appropriate thicknesses and height will be used to segregate different zones of explosives.

12.6.7 Explosives, fuse or fuse lighters shall not be stored in a damp or wet place or near oil, gasoline, or near radiators, steam pipes or other sources of heat.

12.6.8 Smoking and use of matches, naked lights and readily flammable articles or open fire/flame shall be prohibited with in the fenced area around it. Similarly explosives should be kept away from electric contact, fuse boxes and switches.

12.6.9 An area upto a distance of not less than 50 m on all sides of a magazine shall be maintained free of all vegetation, debris and combustibles.

12.6.10 Metals, metallic objects and metal tools that are capable of producing sparks shall not be stored or used inside or in the immediate vicinity of the magazine.

12.6.11 Boxes of explosives shall not be thrown down or dragged along the floor and may be stacked on wooden trestles.

12.6.12 Package containing explosives shall not be allowed to remain in the sun.

12.6.13 Empty boxes, packing materials or any combustible material shall not be stored inside or in the vicinity of the magazine.

12.6.14 Adequate quantity of water and firefighting equipment shall be provided near the magazine. Guards shall be properly trained in handling such equipment.

12.6.15 Signboards reading "DANGER-HIGH EXPLOSIVES", "PROTECTED AREA" "NO SMOKING" etc. shall be prominently displayed In front of the magazine.

12.6.16 Well trained preferably armed guards shall be posted to guard the magazine.

12.6.17 The following shall be hung up in the lobby of the magazine:

a) A copy of explosive rules
b) A statement showing the stock in the magazine, and
c) Certificate showing the last date of testing of the lightening conductor

12.6.18 Magazine shoes, without nails, shall be kept at all times in the magazine and a wooden tub or cement trough, approximately 300 mm high and 450 mm in diameter, filled with water shall be fixed near the door of the magazine. Persons entering the magazine shall put on the magazine shoes provided for the purpose and be careful is not to allow the magazine shoes to touch the ground outside clear floor. Persons with bare feet shall, before entering the magazine, dip their feet in water and then step direct from the tub on to the clean floor.

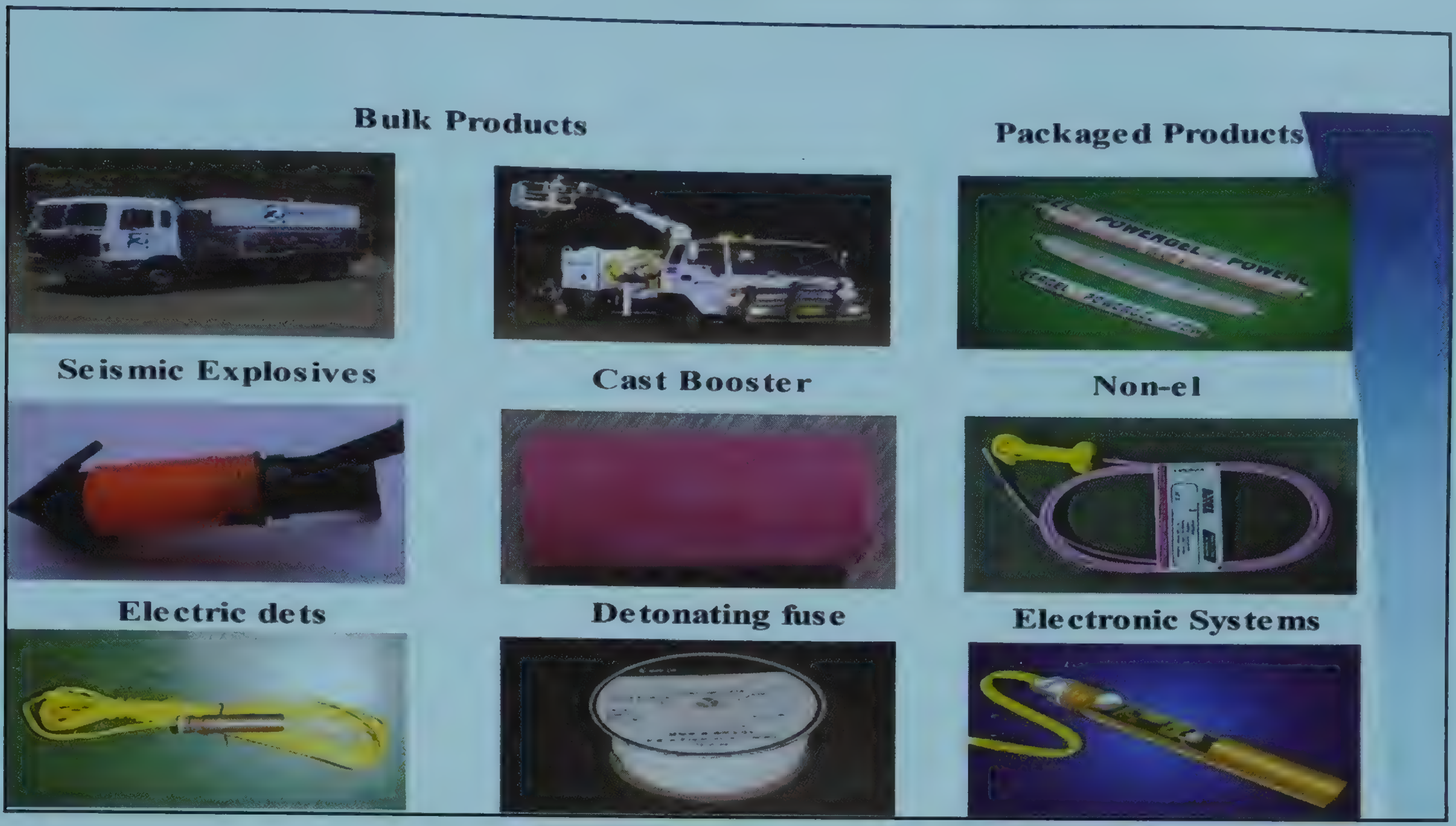
12.6.19 For continued blasting operations the magazine shall be located at a safe distance near the work site and actual requirement of explosives for each blast may be drawn and transported to the site and left-overs, if any, must be immediately returned to the magazine. Where the blasting operations extend to several scattered sites and/or one for a short duration, portable magazines shall be used. Each such magazine shall be located at a safe distance from the work site, enclosed in a fence and properly guarded.

12.7 Methods of Blasting

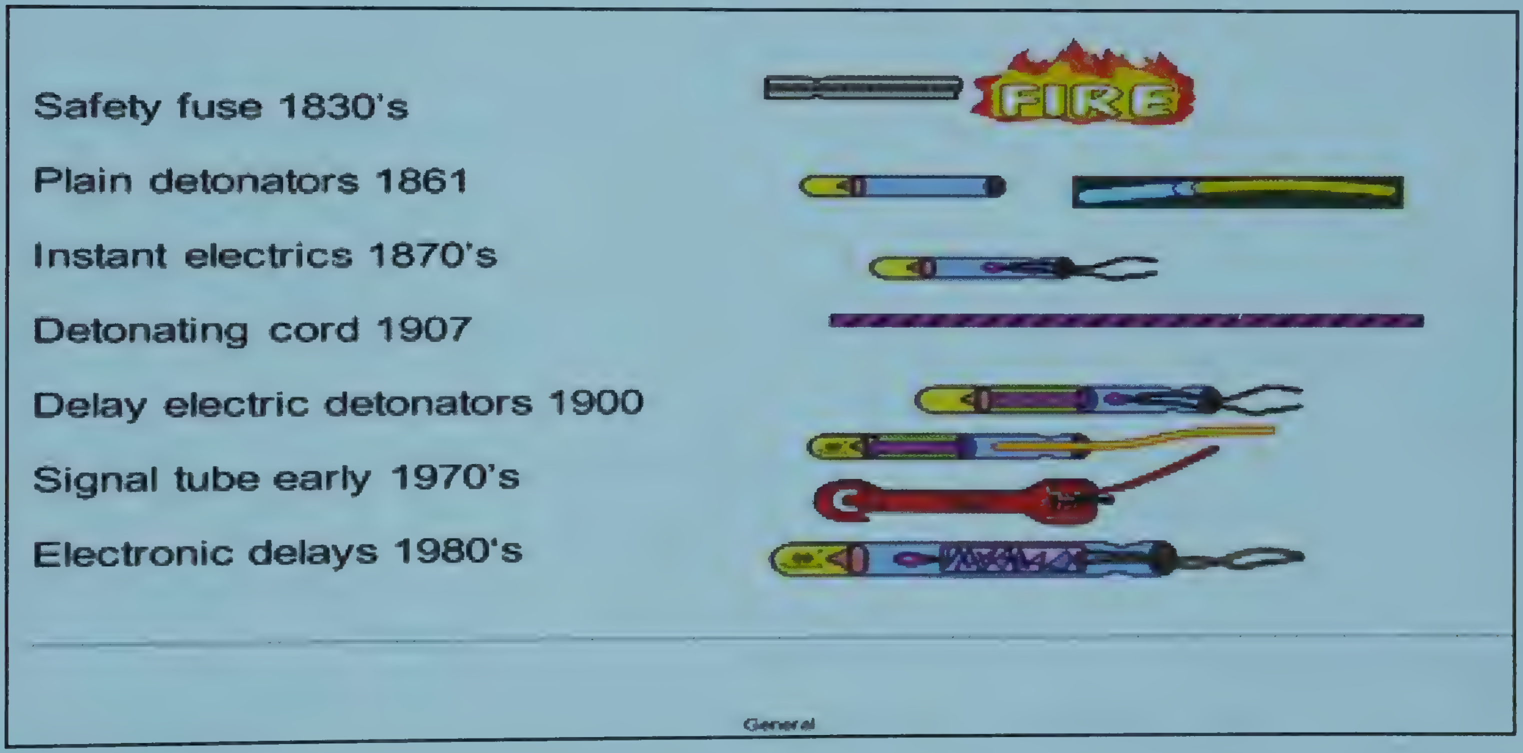
12.7.1 *Blasting Operation Components*

Following are the main components of any blasting operations:

(a) Explosives: Explosives are available in Packaged and Bulk form


Bulk Products
Packaged Products
Seismic Explosives
Cast Booster
Non-el
Electric dets
Detonating fuse
Electronic Systems

(b) Initiation System: Initiation System are the accessories which are required to initiate the explosives for detonation.


Safety fuse 1830's
FIRE
Plain detonators 1861
Instant electrics 1870's
Detonating cord 1907
Delay electric detonators 1900
Signal tube early 1970's
Electronic delays 1980's
General

High explosives are initiated by plain detonators in conjunction with safety fuse, by ordinary electric detonators, delay detonators or by detonating fuse.

Development in Initiation System:

12.7.2 *Blasting with Safety Fuse*

(i) A cartridge of explosives containing a detonator is known as a 'primer' cartridge. Only one primer is required in any one shot hole, irrespective of the number of other cartridges used therein. Where gelatin explosive is used, primer cartridge is generally the top cartridge.

(ii) Preparing the 'Primer' Cartridge

All the saw-dust should be shaken out of the detonator. The safety fuse should be cut straight across with a sharp clean knife. The newly cut fuse should be pushed into the detonator holding it away and the detonator crimped securely to the fuse with a crimper, ensuring not to crimp the detonator tube on the part which contains the detonating composition. The length of crimp should be 3 mm to 6 mm from the open end of the tube. The cartridge should be opened at one end and a hole made with a pricker. The detonator should be pushed in until it is buried, the open end closed and the paper tied round the fuse with a piece of string. The other end of safety fuse should be cut at an angle or scarp for easy lighting.

(iii) Method described above is illustrated in **Fig. 12.2.**

(iv) Charging and Firing

Following accessories are required:

a) Stemming rod: Made of wood (not metal) to charge and stem the hole.

b) Scraper: Made of brass (no other metal) to clean the holes.

c) Pricker: Made of brass, aluminum or wood to prick the cartridge prior to inserting the detonator or detonating fuse.

d) Crimper: Made of non-ferrous non-sparking material for crimping the detonator to the fuse.

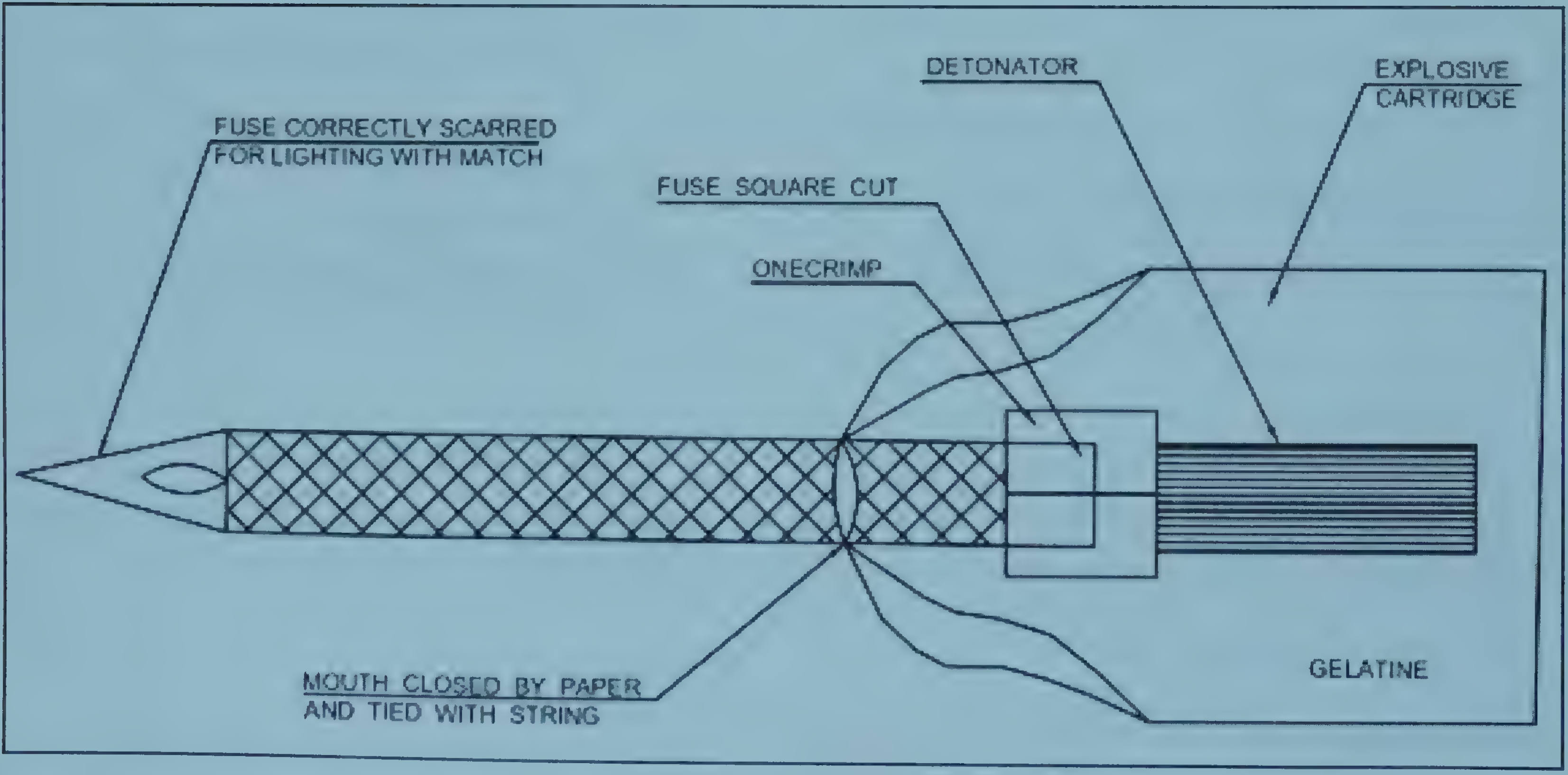

DETONATOR
EXPLOSIVE CARTRIDGE
FUSE CORRECTLY SCARRED FOR LIGHTING WITH MATCH
FUSE SQUARE CUT
ONECRIMP
GELATINE
MOUTH CLOSED BY PAPER AND TIED WITH STRING

Fig. 12.2 Fixing Detonator, Safety Fuse and Explosive Cartridge

(v) The holes are drilled in rock with Jack hammer operated with the help of a compressor. The holes are generally 20 mm to 40 mm dia and 1 to 3 m deep.

The holes can be drilled vertical, horizontal or at any angle. The holes should be cleaned first with compressed air or scraper. The diameter of the hole should be at least 3 mm more than the cartridge diameter. The primer cartridge should be made. Sufficiently long fuses should be used to enable men to get clear after lighting the fuse. If a total of say, three cartridges are required in a hole, then two cartridges should be inserted followed by the primer. The 'primer' cartridge is always the last. The base of the detonator should point towards the full length of the charge. The cartridges should be pushed in one by one with a wooden stemming rod.

(vi) After charging, the hole should be stemmed with sand or a mixture of sand and clay. The first few inches of stemming should be tamped gently with the wooden rod increasing the pressure as the shot holes get filled. Stemming material should be free from sharp particles. The fuse should not be damaged or pulled while stemming. It should be ensured that all personnel have taken shelter before going to light the fuse. After lighting the fuse with a flame, moving to a place of safety away atleast 100 metres from the direction of the blast from the shot holes is essential.

12.7.3 *Electric Shot-Firing*

(i) This method of initiation is safer than blasting with safety fuse since the blaster is definitely out of the way of danger at the time of the blast. Electric shot firing allows upto 200 shots to be fired at a time and with this method the possibilities of misfires are also remote.

(ii) Preparing the primer cartridge

The detonator leading wires should be straightened. A hole should be made with the pricker in one end of the cartridge. (For plain detonators the cartridge end is opened, but with electric detonator this is not necessary). The detonator should be inserted inside the hole until it is burried. The wires are then hitched round the cartridge to prevent the detonator from being withdrawn.

(iii) Charging and firing

For firing a single shot, the procedure is very simple. The hole should be charged with the requisite number of cartridges, inserting the primer last. After the hole has been stemmed, the bare ends of the detonator lead wires should be connected to the firing cable. Moving to the firing station, the other end of the cable should be connected to the exploder and fired. Finally the firing key should be removed and the cable from the exploder disconnected.

(iv) For firing two or more shots at a time, the lead wires are connected in a series circuit. The series circuit is made by connecting one wire from each detonator to one wire of the succeeding detonator and so on, thus forming a continuous circuit. The free wires at either end are then connected to the shot firing cable and the circuit tested with an ohmmeter prior to firing.

(v) In damp conditions, each joint should be insulated to prevent current leakages which might cause misfires and also as a safeguard against stray currents.

(vi) While blasting with safety fuse, the shots in a round do not go off simultaneously. There is usually a short interval between each shot. With electric shot firing, however, all the shots in a round explode simultaneously and only one shot is heard.

12.7.4 *Blasting with Delay Detonators*

(i) Short delay detonators are more suitable for blasting in road construction, excavations and quarrying.

(ii) Charging and Firing

The primer cartridge is prepared in exactly the same way as with an ordinary electric detonator. With ordinary electric detonators, the 'Primer' is inserted into the shot hole last. With delay detonators however, the primer is inserted first, followed by other cartridges. The base of the detonator should point towards the mouth of the hole. The wires should be connected up in series. It does not matter whether the lead wire of a No. 1 delay is connected with that of a No. 7 or a No. 2 delay; as long as the series circuit is properly made, the detonators will explode at the appropriate intervals.

(iii) Advantages of Short-Delay Blasting

The technique of short-delay blasting offers a number of advantages over simultaneous blasting, particularly in reducing ground vibrations and improving fragmentation as given below:

a) Reducing of ground vibration: In blasting for road construction in unstable rock formations, c& should be taken to avoid excessive vibrations. Short delay detonators could also be used when blasting in the vicinity of buildings and structures. The magnitude of the vibrations produced by 5 kg of explosives fired by ordinary detonators is more than that resulting from 75 kg fired with a combination of No. 0 to No. 10 short delay detonators.

b) Multi-row firing: Firing with ordinary detonators, only one row of holes can be fired satisfactorily at a time. To fire several rows, some form of delay is necessary. With delay detonators, the second row fires after the first row has been broken and the third row comes into action after the first two rows have been displaced and so on.

c) Less boulders: Very few boulders are produced with short delay blasting.

d) Less back break: With instantaneous blasting by ordinary detention the area behind the shot holes is likely to be badly cracked. These cracks may cause the roadside wall to collapse at a later date. By using short delay detonators, back break or back cracking can be reduced.

12.7.5 *Blasting with Detonating Fuse*

(i) Detonating fuse is the simplest and safest accessory for initiating explosive charges. It is not normally economical to use detonating fuse in short jack hammer holes. In certain cases however, where speed is essential, the time required for charging and blasting can be considerably reduced with the use of detonating fuse. A large number of shots connected with detonating fuse can be initiated by a single detonator, thus eliminating the length and complicated procedure of electrical connections or of lighting fuses. The process of blasting with detonating fuse is comparatively costly and its use may not be economical in some cases.

(ii) Preparing the Primer Cartridge

A suitable hole should be made with a pricker through the primer cartridge, longitudinally in the case of special gelatins. A piece of detonating fuse of suitable length should then be threaded through the cartridge and the projecting end secured to it by a knot or by taping it to the side of the cartridge so that it cannot be pulled out. The methods for this are illustrated in **Fig. 12.3.**

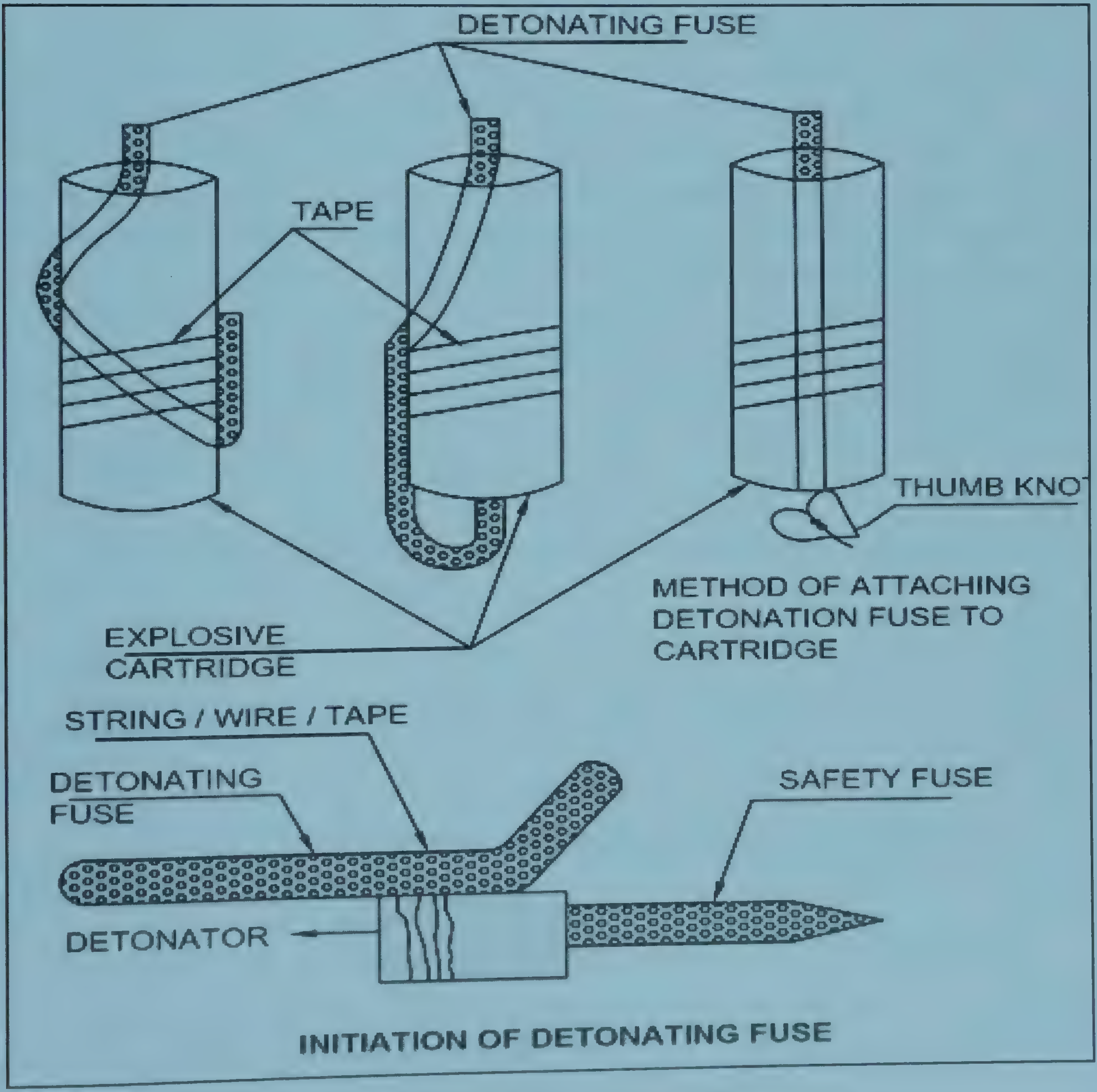

DETONATING FUSE
TAPE
THUMB KNO
EXPLOSIVE CARTRIDGE
METHOD OF ATTACHING DETONATION FUSE TO CARTRIDGE
STRING / WIRE / TAPE
DETONATING FUSE
SAFETY FUSE
DETONATOR
INITIATION OF DETONATING FUSE

Fig.12.3 Blasting with Detonating Fuse

(iii) Connecting and Initiation Detonating Fuse

For charging the holes, the procedure is similar to that adopted for blasting with plain or electric detonators. When the holes have been stemmed, about 15 to 25 cm of detonating fuse should remain outside each hole. A long piece of detonating fuse known as a main line or trunk line should then be laid alongside the holes and the short pieces of detonating fuse connected to the main line. An 'L' joint or a clove-hitch joint can be used for connecting branch lines to the main line. This can be initiated by all types of detonators. The detonator secured to one end of the main line by adhesive tape, should point towards the charges.

12.8 Blasting Technique

12.8.1 *Design Concept*

The design of an efficient blast depends upon the relationship between the diameter and depth of hole, spacing, burden etc. In order to ensure that each cartridge of explosives does maximum work for given working conditions, systematic trials are essential to arrive at the best blasting technique. However, some important general principles are given hereunder.

12.8.2 *Drilling*

It is necessary to have a free face of the rock forming a 'bench' for ensuring effective utilization of explosives. This is done by developing a free face first and then drilling rows of shot-holes, parallel to the free face, 1.5 to 1.7 metres deep and blasting them. The holes in the middle two rows are inclined so as to form a wedge as illustrated in the **Fig. 12.4**. These inclined holes are blasted first, followed by other holes, fired in sequence. The resulting excavation is about 1.5 metres deep and can be deepened further using similar blasting pattern.

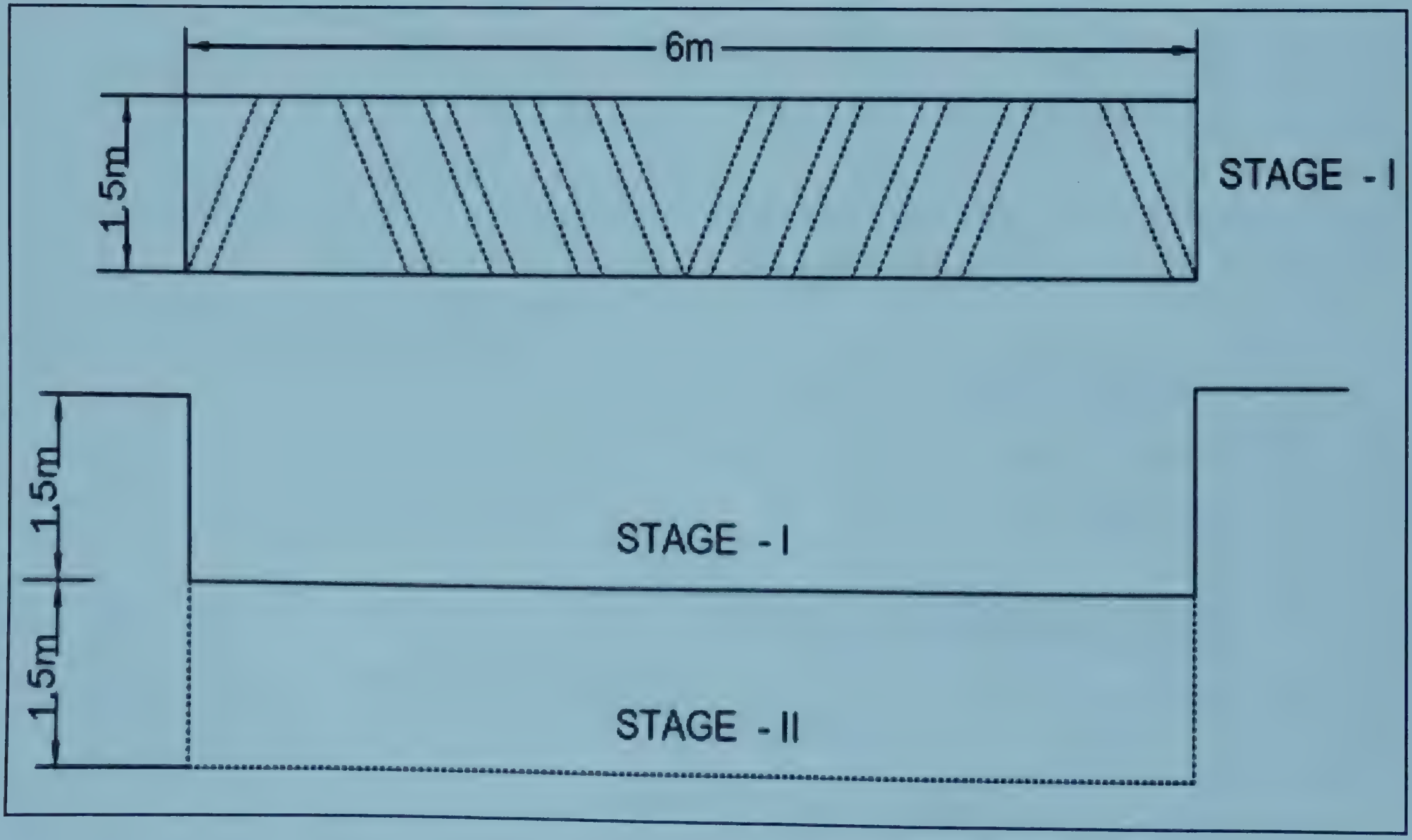


Fig. 12.4 Drilling in Stages

12.8.3 *Burden*

This is the most critical parameter in benching. 'Burden' is the perpendicular distance from shot hole to the nearest free face of the rock in the direction in which the displacement is most likely to occur. Its actual value will depend upon a combination of variables including rock characteristics, the nature of explosive and the diameter of explosive etc.

12.8.4 *Depth of Holes*

The depth of a drill hole depends upon type of drilling equipment and loading method adopted. In case of manual loading the bench height should not exceed 2-3 metres and depth of hole should be kept 3-4 metres, while using jack hammers. As a rule, the depth of hole should never be less than the 'Burden'. In practice holes are drilled to a depth varying from 1.5-2.5 times the 'Burden'. While deciding the depth of drill holes it must be borne in mind that depth of stemming should not be less than the 'Burden'; otherwise Line of Least Resistance will be established in the direction of stemming and blasting may not be much effective.

(i) In general, a few deep bore holes are more efficient than large number of shallow ones as the amount of material detached is proportional to the cube of the depth of the charge. Also the vertical holes are easy to drill and normally give best results. They should be so placed that the Line of Least Resistance is horizontal.

12.8.5 *Spacing of Holes*

The spacing between holes is dependent upon the nature of rock, degree of fragmentation required and the method of firing. Where holes are fired singly or with large intervals, the spacing may be twice the 'Burden'. However, where shot holes are fired simultaneously, which is the most common practice, spacing should not exceed 1.5 times the 'Burden'. In very hard and tough rocks, the spacing may have to be less than the 'Burden'. The optimum spacing between drilled holes should be determined by trials.

Example: Drill Hole Diameter - 32 mm

Depth of hole - 2 m

Burden - 1 to 1.2 m

Spacing - 1 to 1.5m

12.9 Calculation for Blasting and Volume of Rock Blasted

12.9.1 *Volume of rock blasted*

The volume of rock blasted is proportional to the depth and spacing of drill holes and burden and is given by the formula:

Volume of rock blasted per hole (Cum) = Depth (m) x Burden (m) x Spacing (m)

(i) For jack hammer holes it is not necessary to calculate the volume per individual hole. The total volume to be blasted may be calculated as follows:-

Total volume of rock (Cum) = Average depth (m) x Total length of face (m) x Average burden (m)

12.9.2 *Blasting Ratio*

The volume of rock broken by a unit weight of explosive is known as "Blasting Ratio". This ratio is usually expressed in "Cum of rock broken per kg of explosives". For blasting with gelatine 80%, the following ratios may be adopted:-

Very Hard Rock - 1 kg explosive for 3 Cum of rock

Medium Rock - 1 kg explosive for 4 Cum of rock

12.9.3 *Quantity of Explosives required*

The quantity of explosives required per hole or per blast can be worked out as follows:-

$$\text{Quantity of explosives(kg)} = \frac{\text{Volume of rock (cu.m.)}}{\text{Blasting ratio (cu.m.)}}$$

Example 1: Ten jack hammer holes are expected to break 20 cu. m (solid) of medium hard rock. What will be the charge per hole?

Volume of rock - 20 cu.m.

Blasting Ratio - 4 cu.m. per kg.

Therefore, total charge in 10 holes - 20/4 = 5 kg

Therefore, charge in each hole = 5/10 = 1/2 kg

Example 2: 32 mm dia drill holes is 2 m deep, with 1.5 m

Burden and 1.5 m spacing in Hard Rock

Volume of Rock = 2 x 1.5 x 1.5 = 4.5 cu.m. per hole

Blasting Ratio = 3 Total charge = 4.5/3 = 1.5 kg explosive

12.10 Secondary Blasting

12.10.1 Secondary blasting sometimes becomes necessary in the following cases:

a) To break oversize boulders produced during the primary blast to suitable size.

b) To break oversize boulders in land-slides causing road blockades.

12.10.2 There are two basic methods of secondary blasting viz. Pop Shooting and Plaster Shooting.

12.10.2.1 Pop shooting

Pop shooting consists of drilling a hole just close to the centre of the boulder to be broken so that the charge is centrally situated and depth of hole a little more than half the thickness of the boulder. A hole is drilled either manually with the help of a cold chisel or with a hand drill or compressor drill as the situation may permit.

(i) The charge varies with the size of the boulder, but for average conditions, a boulder of size 1.4 m x 1.4 m x 1 m requires a charge of 140 gm i.e. one cartridge of blasting gelatine 80% for every two cu.m. of the boulder. The shots can be fired by safety fuse alone or in conjunction with detonating fuse.

(ii) Machines/equipment etc. deployed on the road near the site should be withdrawn to safer distances, since there is considerable scatter of rock when firing pop shots.

12.10.2.2 Plaster shooting (mud capping)

Plaster shooting also known as 'Pressure Blasting' provides a ready means of breaking even large boulders in circumstances where drilling is difficult due to expediency, or due to non-availability of drilling tools/equipment at sites such as isolated landslides. A charge of one or more cartridges is primed with a detonator and safety fuse, and laid on the surface of the boulder. It is then covered with a shovel-full of plastic clay which is pressed into position by hand. It should be in good contact with the surface around the explosive charge.

(i) In plaster shooting, the charge used is about four times that required for pop shooting, primarily depending upon the thickness of the boulder. **Table 12.2** gives a guide to the quantity of explosive required for different boulder thicknesses although it will vary with the type of rock blasted. Best results in plaster shooting are obtained when the rock is-of a hard and brittle nature.

Table 12.2. Quantity of Explosives Required for Plaster Shooting

Thickness of Boulder (cm)	Charge in gm
Upto 40	100
40-70	200
70-90	300
90-110	400
110-140	400-700

12.11 Blasting Methods for Different Road Construction Activities

12.11.1 *New Roads*

The most convenient method is to drill vertical holes in several parallel rows across the roadside face of hill to obtain 'benching'. A series of benches can be established to achieve the full height of the cutting. The height of the benches will vary depending upon the type of the drilling equipment available and with jack hammers it rarely exceeds 3 metres. For fast advance of the benches, multi-row firing is often useful. The method is illustrated in **Fig. 12.5.**

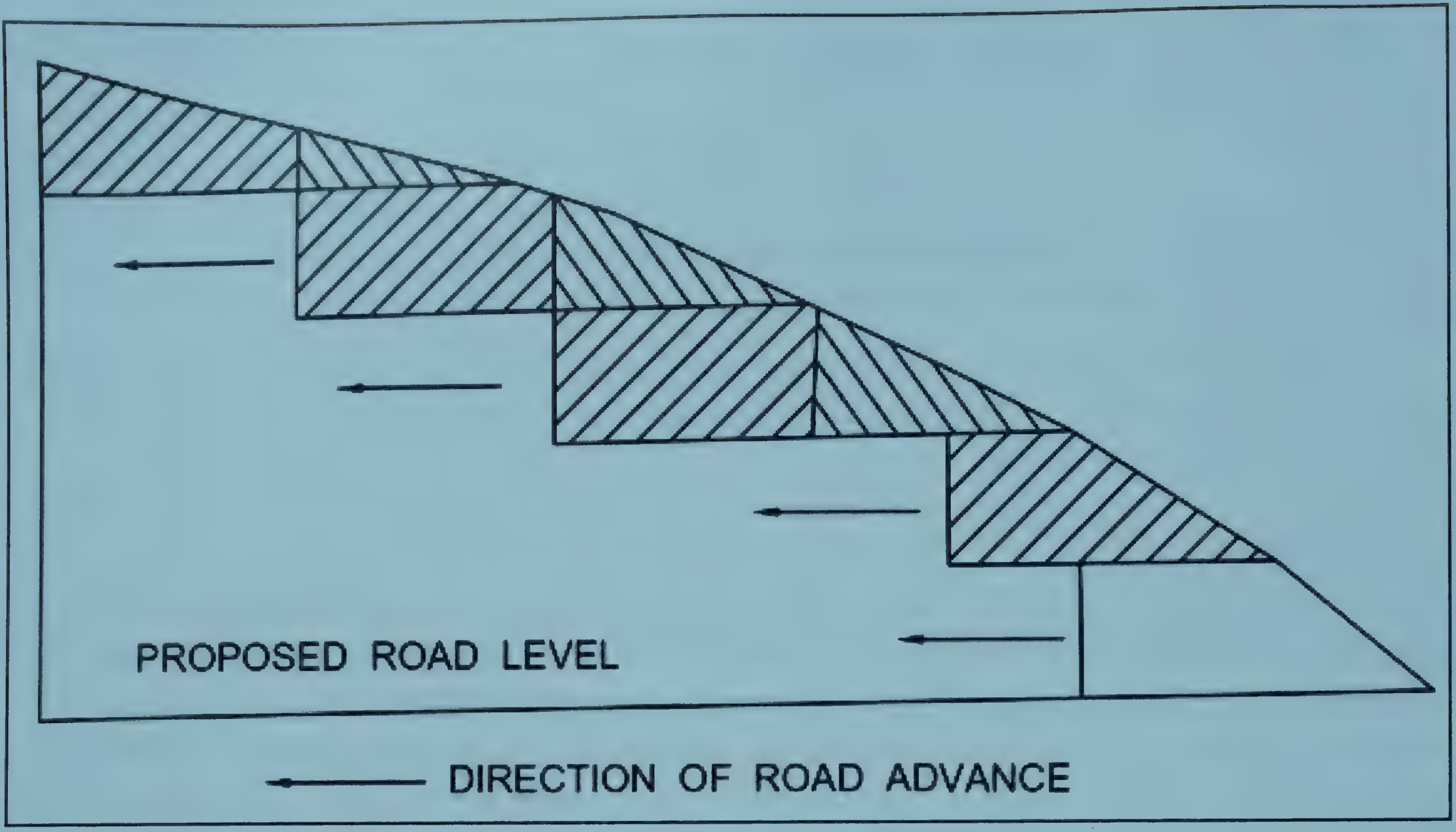


Fig. 12.5 Rock Excavation by Benching

(i) Cuttings

There are two general types of cuts, a side hill cut where the excavation is made on the side of the hill leaving a wall on one side only and a through cut, where the excavation is made through a hill leaving a wall on both sides. The procedure is described below:-

a) Side Hill Cuts: The first operation is the removal of soft over-burden. This is carried out in advance of the rock excavation, to facilitate drilling of the rock. When the rock has been exposed, a free face is established across the width of the cutting. This is done by two or more parallel rows of vertical holes and charging and firing them simultaneously. Once the free face has been established, the work proceeds by blasting successive rows of holes drilled parallel to it. For deep cuttings. the desired level of road can be reached by excavating in several lifts.

b) Through cut: In case of through cut, a long cut can be opened up along the centre line on either side depending on the slope of the surface. This face is then worked as a quarry and pushed back laterally to the slope line. This method can be repeated on successive lifts until the cut becomes too narrow. After that, the through cut is worked in the normal manner that is, with the shots extending to the full width.

12.11.2 *Half-tunneling*

Half tunnels are made where the strata is particularly strong and where construction of an open road would entail prohibitive amount of rock excavation. The width and height of half-tunnels (and full tunnels) should also consider future requirements of widening etc. as hill cutting later on will be very inconvenient and too costly. The half tunnel should be 7 m or more wide and

5-6 m high. Jack hammer drills fitted with air legs are most suitable for drilling the horizontal holes required for half-tunnelling. For drilling holes in the upper section of the cave, a portable staging with several platforms will be necessary. Alternatively, where the half tunnels are not very high, the upper holes can be drilled by standing on the debris produced by an earlier blast. Horizontal holes drilled parallel to the hill-side should be 1.6 to 2 m deep and fired with short delay detonators. A typical half tunnel face showing hole placement and distribution of short delay detonators is illustrated in **Fig. 12.6.**

12.11.3 *Tunneling (full)/Drifting*

A variety of drilling patterns are adopted in tunneling work. The usual procedure is to fire several shots to break out a preliminary cavity known as 'cut', in the centre of the cross section. This is further widened by means of easer shots and final trimmer shots are fired to bring the tunnel to the required finished size. The type of cuts commonly used include pyramid cut, drag cut and burn cut depending upon the nature of rock.

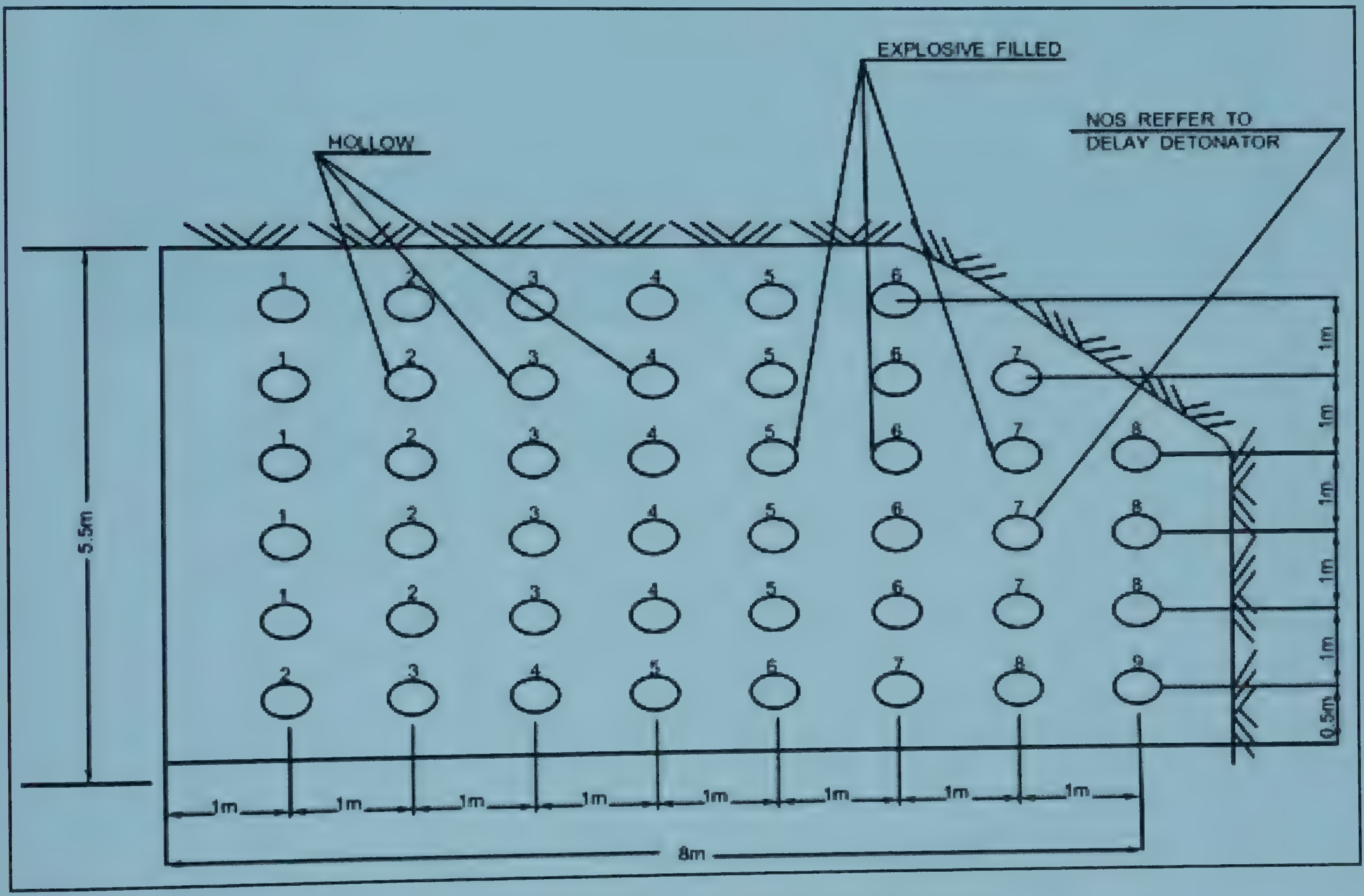


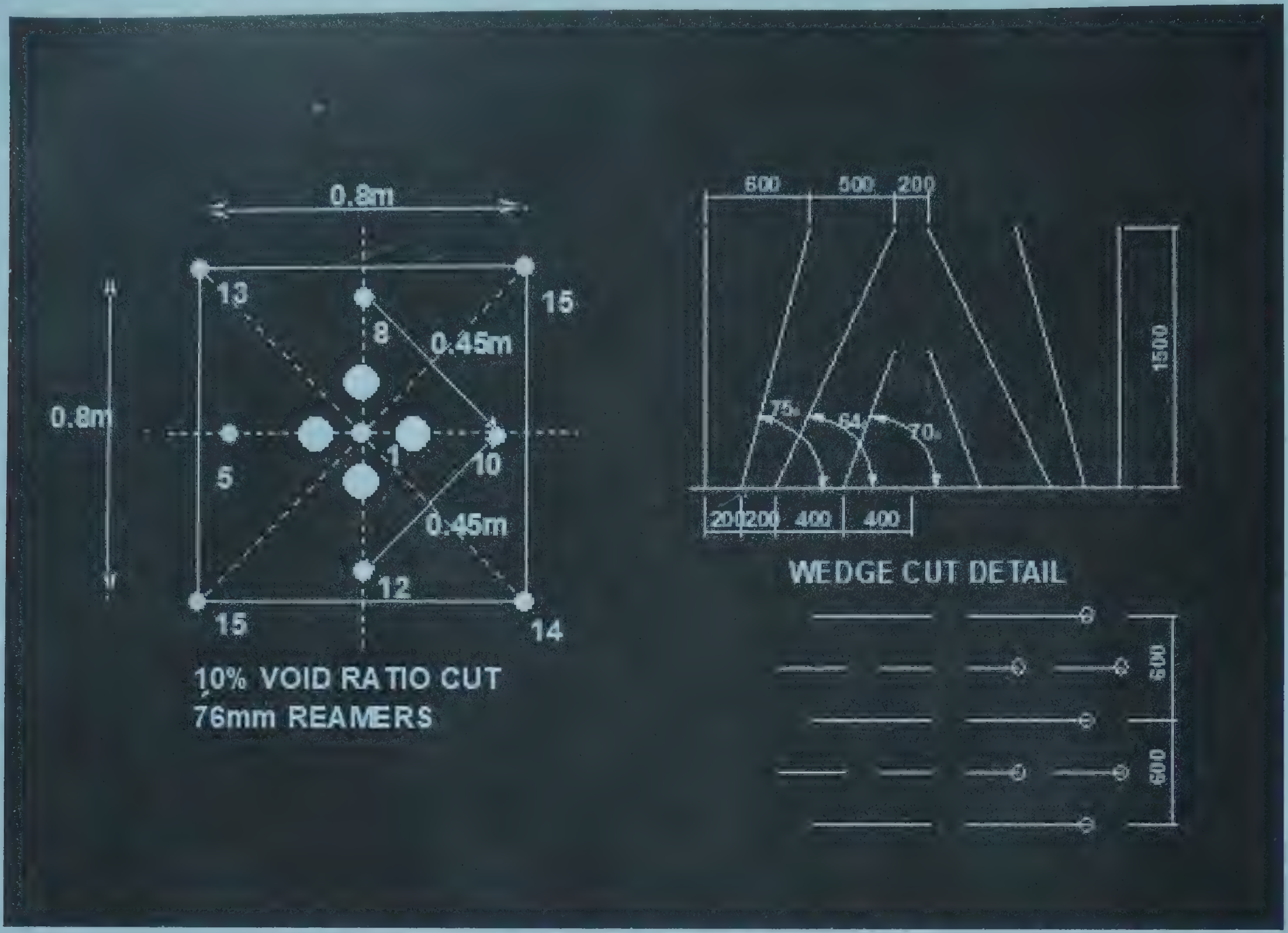
Fig. 12.6 Section of Half Tunnel Face

These are described below:

a) Pyramid cut: A typical arrangement is given in **Fig. 12.7**. Due to the inclination of the holes. the depth of the cut is generally restricted to half the width of the drift.

b) Wedge cut: A typical system is given in **Fig. 12.8**. The holes are inclined at an angle not less than 45^0 towards the centre and almost meeting at the back of the cut. In large tunnels a double wedge cut is often used i.e. a small wedge followed by a larger one.

Note: *Both pyramid and wedge cuts are suitable for uniform bedded hard rocks. Explosives consumption is less than for other types of cut, but the depth of pull is restricted by the width of the drift.*


0.8m
0.8m
13
15
8
0.45m
5
1
10
0.45m
12
15
14
10% VOID RATIO CUT
76mm REAMERS
600
500
200
1500
75
64
70
200
200
400
400
WEDGE CUT DETAIL
600
600

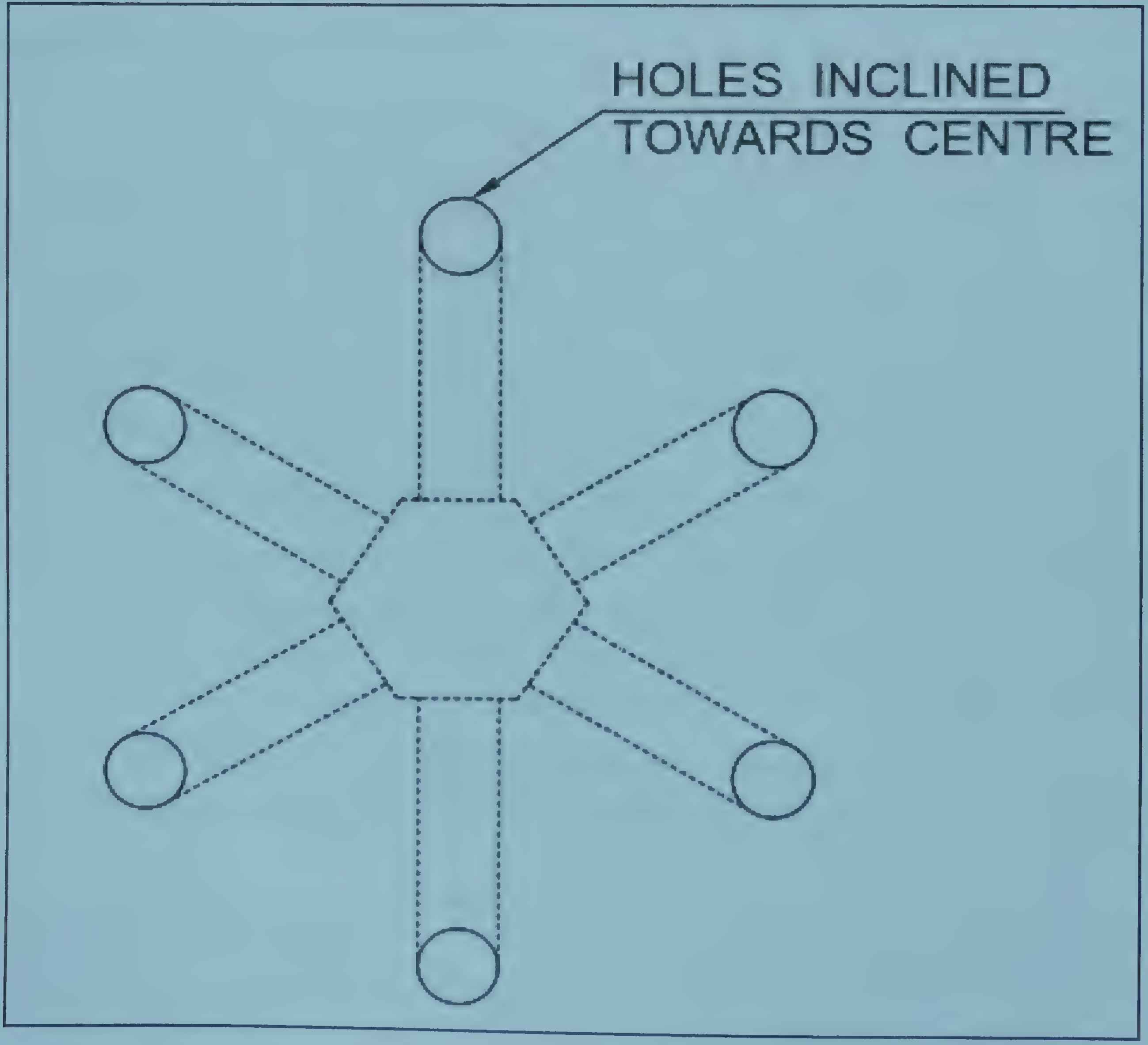

HOLES INCLINED TOWARDS CENTRE

Fig. 12.7 Pyramid Cut

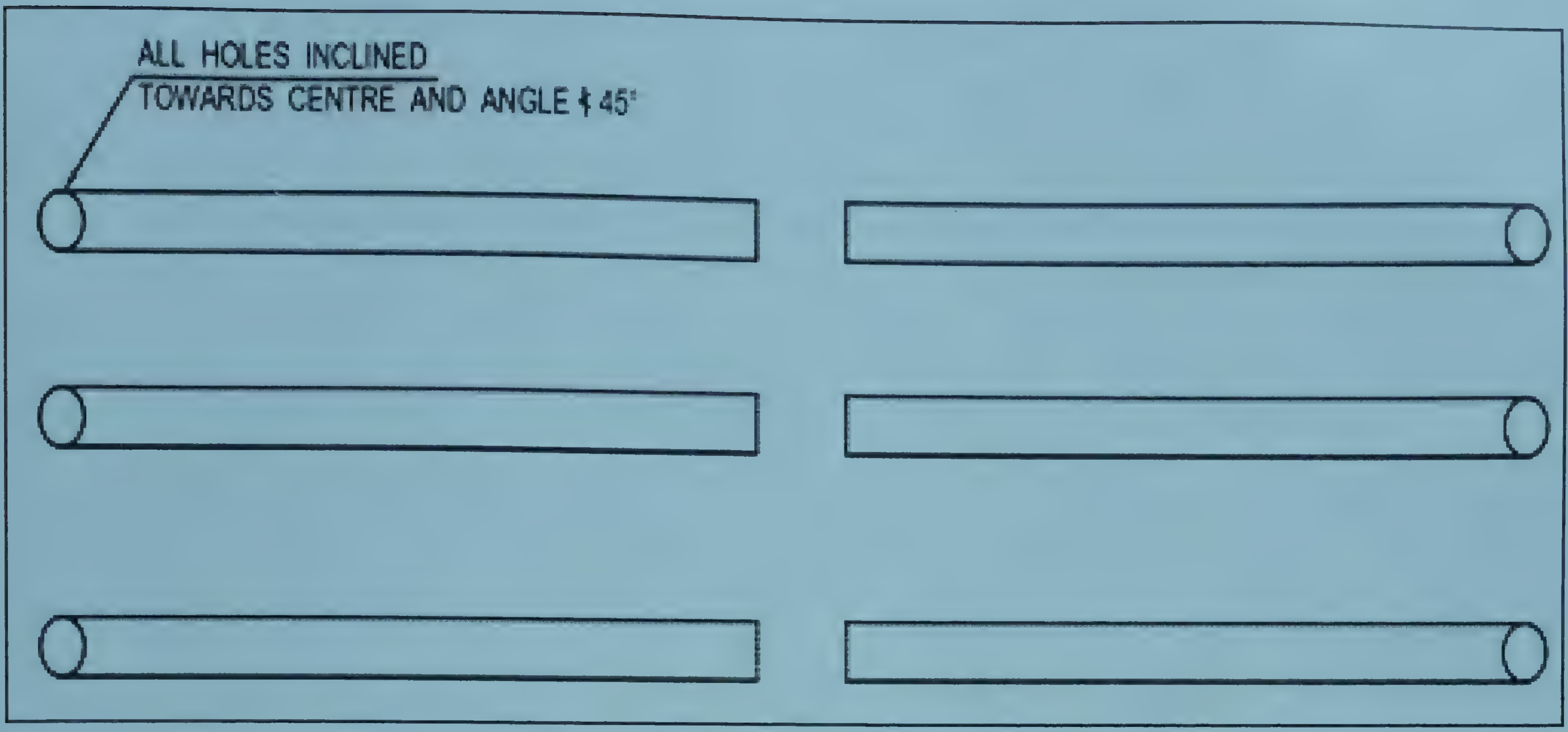

ALL HOLES INCLINED
TOWARDS CENTRE AND ANGLE ≮ 45°

Fig.12.8 Wedge Cut

c) Drag cut: This is mainly used in small drifts. A typical system is given in **Fig. 12.9**. Wherever possible holes are inclined to the cleavage so that strata breaks along these planes. 'D' is not more than H/2 & 'h' is not more than H/3, where D is depth of hole, His height of cut and his height of bottom most hole from ground level.

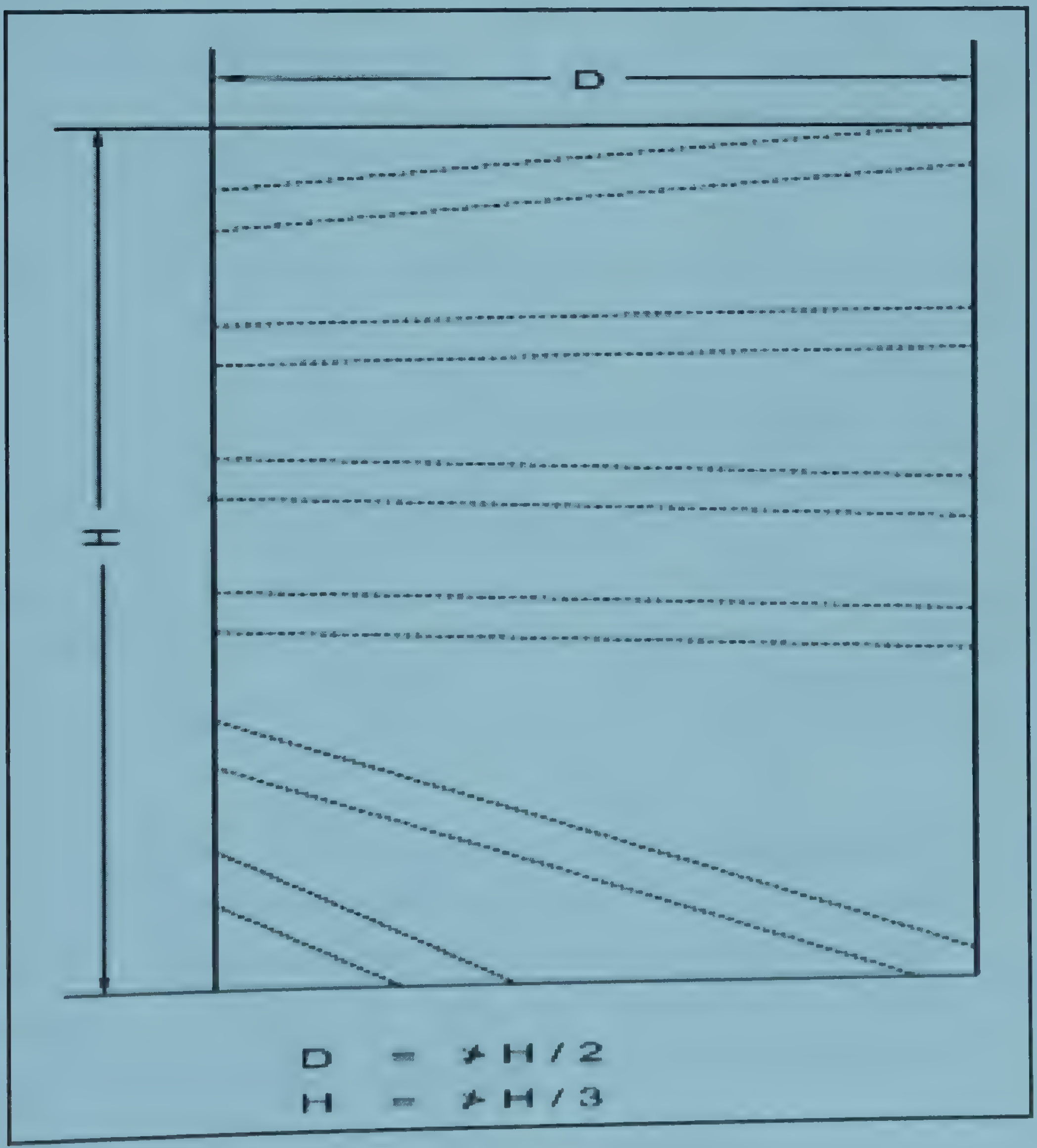


Fig. 12.9 Drag Cut

d) Burn cut: Typical arrangement is given in **Fig. 12.10**. While it is difficult to drill more than half the width of the tunnel with a, b and c above due to angle of drill hole, with the burn cut, advances equal to width of tunnel can be obtained. Burn cut patterns comprise a number of parallel holes of the same diameter, closely spaced, some of which are heavily charged and the remainder left empty to provide a free face.

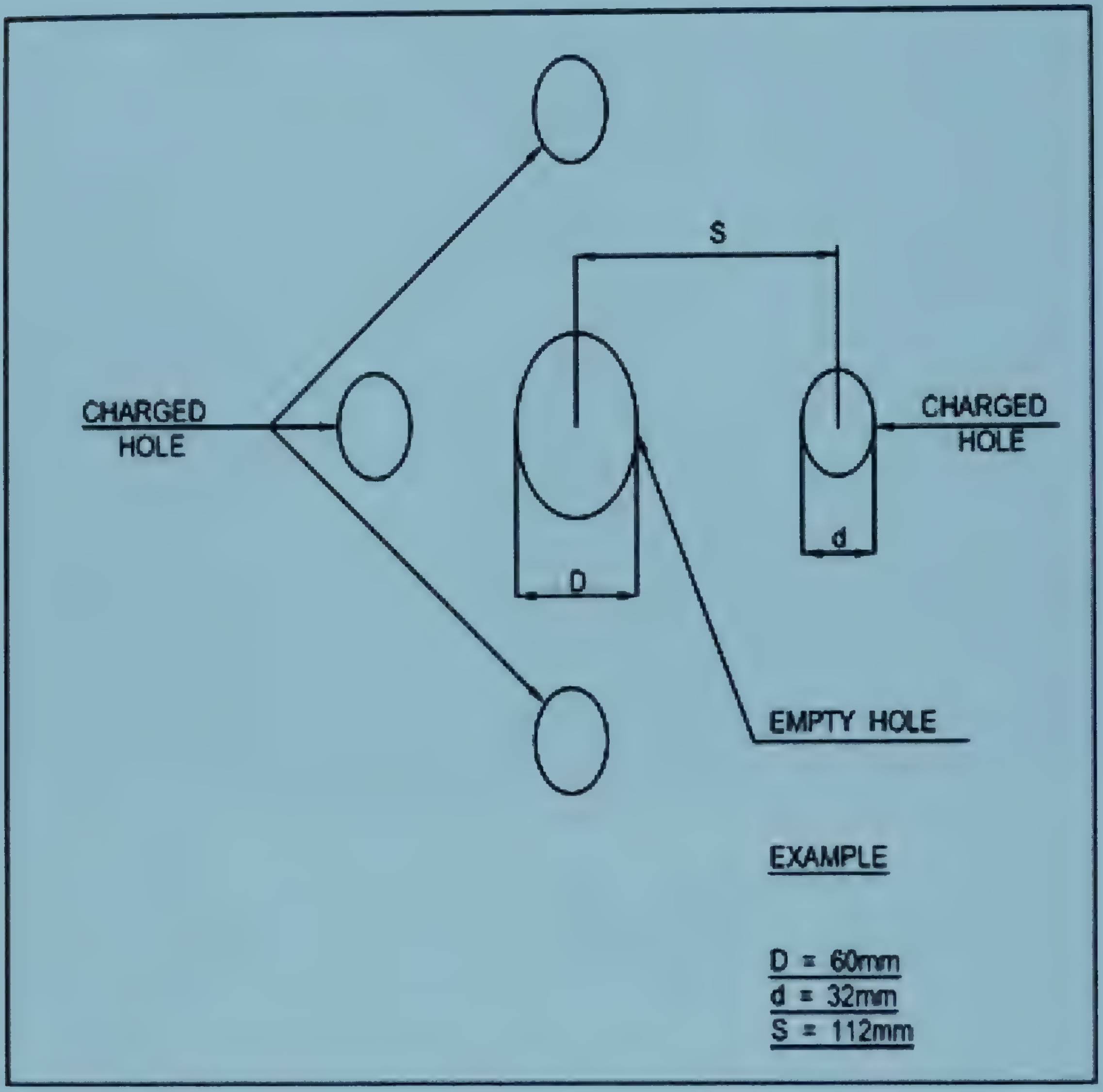


Fig. 12.10 Burn Cut

(i) It is necessary to have a series of charges firing at intervals. This is achieved either by using delay detonators if fired electrically or plastic cord, if fired with safety fuse. Generally special blasting gelatins are best suited for this work. Consumption of gelatin varies from 0.7 - 0.25 kg/cu.m of rock broken depending upon the nature of rock and size of excavation.

(ii) To expedite progress on a long stretch of half tunnel or tunnel, approach tunnels may be driven at intermediate points, at right angles to the direction of the center line of proposed road. This will allow extra tunnel faces to be opened up. Once the faces have advanced away from the tunnel the compressor and other, equipment can be stored in the bye-end.

12.11.4 *Excavation of Rock Foundations*

Excavation of foundations for bridges, piers etc. forms an important part of the road building projects.

(i) First a small pit should be formed by blasting and this can be later enlarged and deepened to the desired limits of excavation. Several pairs of inclined holes should be drilled in the form of a wedge. These holes should be drilled 0.9 to 1.2 m deep at 75 cm center to center and each hole should be charged with two or three 25 mm x 20 cm cartridges of blasting gelatin 80% strength.

(ii) For excavation in low lying areas and river beds the depth of water normally ranges from 3 to 90 cm. Drilling in shallow water is rather difficult and the holes often get filled up with sand and dirt. The depth of holes, therefore, should not be more than 0.9 m. A number of holes should be drilled 0.9 m deep with 6m spacings and each hole should be charged with blasting gelatin 80% strength at a ratio of approximately 1.5 cu.m per kg.

(iii) Detonating fuse may be used for under water blasting and the cartridges should be taped on a thin strip of wood or bamboo. If electric detonators are used then all joints should be properly insulated and kept out of water.

12.11.5 *Well-sinking*

Since conditions in sinking are normally wet, it is important to use high density, water resistant, gelatinous explosives. The principle in sinking is same as in tunneling. An initial cavity is created by blasting a ring of holes inclined towards the center as to form an inverted pyramid. The subsequent ring of 'easers' and 'simper' holes which are succeedingly less inclined than the preceding holes, fire into this cavity. The charge ratio is about 0.45 - 2 kg/cu.m solid rock broken.

12.11.6 *Maintenance of Roads*

Hill roads are sometimes blocked by slips/landslides and also by large boulders sliding down hill. Smaller pieces can be bulldozed away but the large ones often require to be blasted. Both pop shooting and plaster shooting can be applied to break up large boulders.

12.12 Machinery Required for Rock Blasting on Roads

Air compressors of to 6 cu.m/min. capacity are generally used. The accessories required with a compressor are as follows:

a) Jack Hammer - 1 to 3 Nos depending on capacity of the compressors
b) Line lubricator - 1 to 3 Nos
c) Air hose pipe - 100 m
d) Hose pipe couplings - 8 No as required
e) Drill rods (i) 1 m - 6 Nos (ii) - 1.5 m - 6 Nos
f) Grinder for sharpening - 1 No
g) Essential spare parts for jack hammer

12.13 Record of Drilling/Blasting

Record of drilling and blasting may be maintained in the format given in **Table 12.3.**

Table 12.3 Record of Drilling and Blasting

Date.................................Location.................................Rock..................................

Hole No.	Hole Dia (mm)	Height of face (m)	Depth of Hole (m)	Burden (m)	Spacing (m)	Volume of Solid Rock per Hole (cu.m)	Charge per Hole (kg)	Charge Ratio	Detonating Fuse (m)	Detonators (Mention type wise) (Nos)	Remarks

12.14 Blasting in Adverse Weather Conditions

12.14.1 Special measures have to be adopted when blasting in unfavorable weather conditions.

(i) In very cold weather

Low - freezing type explosives can be stored and used upto 0^0C or even at lower temperatures if the exposure is of short duration. Prolonged exposure to lower temperatures may, however, cause the explosives to freeze. On freezing, explosives lose their plasticity and become hard. In frozen state, some types of explosives are very sensitive and liable to premature explosion.

(A) All types of detonators and detonating fuse remain unaffected by low temperatures. The outer coating of safety fuse will freeze in sub-zero temperature conditions.

(B) Precaution to be taken to explosives from freezing

The following precautions should be taken:-

a) Store all explosives in well-constructed magazines until required for use.

b) Stack cases of explosives on wooden trestles clear off the ground.

c) Cover cases of explosives with tarpaulin when awaiting use in the field.

d) Use up the contents of the case quickly once it has been opened.

e) Return all unused explosives to a magazine at the end of the day.

f) Explosives should not be left exposed in the open for longer than is absolutely necessary.

g) As a general rule, explosives should be issued from a magazine on a ‘first-in first-out’ basis.

(C) Precautions to be taken with frozen explosives

The precaution to be taken are:

a) Frozen explosives should not be used for blasting.

b) Pricker should not be forced into a frozen cartridge of explosive.

c) Attempt to soften a frozen cartridge of explosives by pressing it in the hand or rolling it on the ground should not be resorted to.

d) Attempt to thaw frozen-explosives by heating them over an open fire should not be done.

e) Frozen explosives should be thawed by placing them in the sun.

(D) Precautions to be taken with frozen safety fuse

The outer coating of safety fuse is likely to crack if it is stored and uncoiled in very cold weather. Moisture or water may enter through these cracks and affect the black-powder core.

(ii) In Wet Weather

Blasting gelatin is water resistant and can be kept submerged in water for at least 24 hours. Ordinary detonators and safety fuse can be used in wet holes provided the crimps have been treated with cap sealing compound.

a) Blasting with safety fuse cannot be practiced when it is actually raining. Electric shot firing may be carried on provided all the joints have been properly insulated.

b) The most suitable method, of course, is to use detonating fuse for blasting in very wet weather. If the holes contain water, a knot should be tied in the fuse in such a way that about 8-10 cm of fuse extend beyond the knot. A cap sealing compound may be required when holes are likely to contain water. The junction between the fuse and detonator should be properly coated with this compound.

(iii) During Thunderstorms

Blasting should be stopped and all men must leave the blasting site, when an electric storm is approaching. An electrical shot firing circuit, if struck by Lightning may detonate despite all precautions. Lightening several kms away may produce electrical charges sufficient to fire electric detonators. In case the storm is not severe, then the charges primed with detonating fuse can be initiated by plain detonator and safety fuse.

(iv) In Foggy Weather

Shot firing should be suspended during dense fog. Due to poor visibility it becomes difficult to ensure that the danger area has been cleared of men and animals.

(a) In foggy weather it takes a long time for the fumes to clear and workers should not return to the work site until the smoke and fumes have disappeared.

(v). In High Wind

In high wind, as difficulty may be experienced in lighting fuses with ordinary matches, special matches and lighting devices available for this purpose should be used.

12.15 Fly Rocks

Fragments of rock always fly as a result of blasts. These fragments should not be allowed to fly dangerously when blasting near villages or buildings etc. Fly rock can be prevented by placing blasting mats on top of the area being fired. These are heavy large mats in various sizes and can be made from 2 to 4 cm manila rope or old steel wire rope or old rubber tyres etc. These mats catch or arrest the fly rock. Holes should be omewhat under-charged in order to avoid fly rock. Only two or three shot holes should be fired at a time, with minimum quantity of explosive just to crack/break the rock.

12.16 Misfires

In case the proper method of blasting is used, the occurrence of misfire will be very rare. Occasionally, however, the shot firer may encounter a misfired shot and it is important that he should know how to deal with it. It is a general practice to wait for 30 minutes, when blasting with plain detonators, before returning to blasting site and 5 minutes when using electric detonators or delay detonators.

12.16.1 *Cause of Misfires*

These are explained below along with precautions for their prevention:

a) With safety fuse and plain detonators:

Cause	How to prevent
1. Black powder core becoming damp	Store fuse in cool, dry place. Use waterproof fuse in wet holes.
2. Cracking of fuse by uncoiling in very cold weather. Moisture can enter through these cracks.	Warm frozen fuse at 20^0 to 25^0 eight hours before through these cracks.
3. Water entering detonator	Crimp tightly. Use cap sealing compound. Dip the joint in the compound and allow it to dry before making up the primer. Do not use grease for water proofing.
4. Fuse damaged during stemming	Use fine material for stemming and stem gently using a wooden rod.
5. End of fuse may have absorbed moisture	Use freshly cut fuse only.
6. Fuse cut at an angle may double back inside with a sharp knife.	Cut fuse straight across section a detonator.

7. Air gap between detonating compaction and fuse and saw dust or dirt inside detonator.	Remove all saw dust and dirt from Detonators. Make sure that the end of the fuse is in close contact with the detonating compaction.
8. Fuse and detonator may have been pulled out of the primer	Fix fuse securely and test by pulling during stemming.
9. Fuse may have come out of detonator	Use a proper crimper. Do not crip with tooth or ordinary pliers.
10. Fuse may not have lighted.	Be sure that each fuse is burning before lighting the next fuse.
11. Damp detonator	Store detonators in a dry place. Do not blow into a detonator to remove sawdust.

b) With Electric Detonators:

Cause	**How to prevent**
1. Detonator damaged, or lead wire	Store in a dry, well ventilated place corroded due to damp.
2. Broken lead wire	Do not pull or jerk lead wires
3. Detonator pulled out of primer	Stem gently
4. Poor connection causes partial misfire in round	Make clean, firm joints and keep them dry.
5. Faulty exploder or faulty operation of exploder	Check exploder regularly and see that it is capable of firing the required number of shots. Keep exploder dry. Use full force when turning the key
6. Insulation scraping off causing and stem gently	Avoid sharp particles in stemming short circuit.
7. Lead wire touching rails, pipes etc. Cause earth leakage and short circuit	Keep wire of blasting circuit away from metal objects
8. Bare joints lying in water or on wet ground	Insulate all joints and keep them above wet ground
9. Wrong wires connected with each other	Make proper series connection and check with ohmmeter
10.Cut off with delay detonators	Place primer cartridge at the back or bottom of the hole when using delay detonators.
11 . Faulty cable	Check cable regularly with ohmmeter

12.16.2 *Detecting of Misfired Shots*

While blasting with safety fuse it is easy to locate the misfired shot by simple visual examination. When firing electrically, however, the procedure described below has to be adopted to find the faulty shot.

(i) Where the electric detonators are connected in series, the first step is to divide the circuit at the face in half, connecting one half to the shot firing cable and testing it from the firing point, all men having been withdrawn from blasting site. This procedure will indicate in which half of the circuit, the defect lies. The defective half of the circuit is again halved, the test repeated and the faulty quarter of the circuit discovered. By further repetition of this method, the faulty shot will be finally located. The remaining shots can be fired after taping the leading wires from the defective shot to a suitable marker. A search should be made afterwards for undetonated cartridges and detonator, assuming that the misfired hole has been dislodged during the blast.

12.16.3 *Dealing with Misfired Shots*

Where a misfire occurs with safety fuse, the exposed fuse should be examined after a lapse of thirty minutes. If a sufficient length of sound fuse is found projecting from the hole, then it should be relighted. Where the fuse has burnt to a point inside the stemmed hole, the procedure given below should be adopted. This procedure will also apply to misfires with electric detonator.

(i) Recovering the charge by removal of stemming

Attempts should be made to remove the stemming by blowing out with compressed air or flushing out with water. The air blast or water should be introduced through rubber or non-ferrous metal pipe. No tools should be used for digging out stemming since there is the risk of detonation of the charge by friction or shock. After the stemming has been removed, it may be possible to withdraw remaining cartridges in the shot hole.

(ii) Displacement of charge by relieving holes

If it is not possible to fire the charge by inserting a fresh primer, then a relieving hole, not more than 90 cm deep should be drilled parallel to and atleast 45 cm away from the misfired shot. After firing the relieving shot, the debris must be carefully searched and the undetonated cartridges and detonator recovered.

(iii) Misfired shot containing detonating fuse

With charge in large diameter holes primed with detonating fuse, the stemming should be removed to expose a short length of detonating fuse. A primer should then be secured to the fuse and fired. This will most likely detonate the misfired charge. If, however, the fuse cannot be exposed, then relieving holes, not more than 38 mm diameter and 90 cm depth should be drilled and blasted in such a way that the rock is benched away from around the misfire.

12.17 DO'S and DON'Ts with Explosives

In earlier paragraphs detailed notes have been given on the correct method of handling of explosives, accessories and blasting techniques. DO'S and DON'Ts on the use of explosives, considering safety is given in **Appendix 12.1**

12.18 Caution

Explosives and accessories are sensitive materials and hence blasting operation has inherent risk and danger unless the entire operation is handled with security and safety as prime factor. Utmost care and caution should be exercised in handling and use of explosives and laid down procedures strictly adhered to.

13. ECOLOGY AND ENVIRONMENT

13.1 General

13.1.1 Development in terms of environment consequent to the realization that the environment was deteriorating and earth's resources were fast depleting threatening man's survival on earth itself has given rise to serious universal thought on preservation of environment and maintenance of a balanced eco-system.

13.1.2 Development without destruction" in pursuance of the national priority to create a balance between ecology and development is of utmost importance. While constructing roads for the development and prosperity of the nation, it has to be ensured that the eco-system is not disturbed and a harmonious, balance struck between road development and environment.

13.2 Definition and Introduction

13.2.1 Environment includes water, air, land and all items forming part of surroundings whereas ecology is the relationship between organisms i.e. human beings, living creatures, plants, micro-organisms, etc. Thus environment will include ecological resources also. Eco-system is the ecological community living together with its physical environment considered as a unit. Disturbance to any of the component factors in a unit environment is likely to upset the ecological balance and lead to destruction. Hence maintenance of ecological balance is of prime concern.

13.2.2 Certain important aspects of environmental degradation that can result in ecological imbalance are given below:

(i) Anything that affects quality of air that we breathe adversely affects general wellbeing of all living creatures, i.e. human, animal and plant life.

(ii) Ozone layer surrounding earth acts as protective filter against harmful rays reaching the earth and any disturbance to this layer tampers with life supporting system and therefore harmful to healthy life.

(iii) Emission of green-house gases i.e. carbon dioxide, nitrous oxide, methane, etc. by human activities and industrialization leading to destruction of patches of ozone layer and consequent global warming, could destroy crop patterns, cause skin diseases, raise water level in oceans and resultant flooding, etc.

(iv) Forest are repositories of the earth's bio-diversity and the millions of species that exist in the forests are natural wealth and is greatly responsible for preservation of the Eco-system. The forests have, therefore, to be preserved even if certain of the forest wealth/resources require to be exploited for development and industrialization.

(v) Pollution of water sources and affecting quality and supply of fresh water sources can affect life and health of living organisms including human beings.

(vi) Climatic changes with disastrous consequences on account of items mentioned above.

(vii) Rapid industrialization, population growth, denuding forest cover, creation of habitation in virgin areas, and development projects affecting not only natural resources, but also people and destruction of naturally stable hills, rivers, lakes, and items of art, culture and heritage. It may be seen from above that any development activity can result in disturbance to the eco-system unless effective measures are taken to ensure that adverse effects are inevitable minimum and adequate mitigation measures are also taken.

13.3 Hill Roads and Environment

13.3.1 All road or highway projects have necessarily to come up on land and hence have an impact on physical and natural resources such as, topography, geology, hydrology, soil, land use, air quality, noise level, surface & ground water, vegetation, forests etc. depending on location of the highway project.

13.3.2 The roads in hilly regions are aligned in forest and mountain areas. In most of these areas survival itself is a fight against nature but the region by themselves are endowed with gifts of nature and environmentally and ecologically fascinating. These areas are treasure houses of flora and fauna, important as tourist and health resorts, pilgrim centres, adventure sports area, habited by under privileged brethren of our land whose advancement and merger into mainstream of national life depends on good road communication. At the same time, these areas are ideal for development schemes also like Hydel projects, flood control etc.

13.3.3 The regions are mostly in unstable terrain conditions subject to extremes of climate and are prone to land-slides, flooding, snowfall, snow drifts, glaciers/avalanche activity and so on which have adverse effect on road system. However, the road system is itself an encroachment on surroundings, disturbing natural state, when this is coupled with adverse conditions situation worsens. As a balanced eco-system is essential for survival of all living species it becomes imperative that when hill roads are developed preservation of environment and ecological balance is a part of the project.

13.4 Impact of Highway Projects on Environment

13.4.1 Highway projects have impact on the physical resources such as drainage, surface water quality, air quality, soils and noise levels. Improper cross drainage can cause swamps on either side of the road embankment possibly leading to increased flood water levels. Water quality can be affected during construction and operation of the highway by run-off of wastes. Pollution can occur through accidents causing spills of transported materials. The air quality can be affected by emission during construction from mobile sources such as vehicles involved in construction activities as also from fixed sources such as stationary construction equipments like stone crushers and hot mix plants. During the operation phase, air quality can be affected by vehicular exhaust. Air pollutants of primary concern include suspended particle matter, nitrogen oxides, carbon monoxide, hydrocarbons and lead. Air pollution impact will be more appreciable in urban and industrial areas.

13.4.2 The possible positive and negative impacts (beneficial and adverse/detrimental) to the environment resulting from a proposed highway project in hilly regions are given in **Table 13.1.**

Table 13.1 Beneficial and Adverse Impacts of Hill Road Projects

Beneficial Impact	Adverse Impact
▪ Socio-economic upliftment of people ▪ Employment opportunity ▪ Education and health care ▪ Income from Tourists & Taxes ▪ Enhancement of rural development through better transportation facilities ▪ Transporting, processing and marketing agricultural products ▪ Opening up new industries and opportunity for new occupation ▪ Approach to quick services and safety ▪ Improved quality of life. Better habitat and housing ▪ Feeling of security and social equality.	● Landslides, erosion and sediment discharge. ● Poor drainage resulting in damage leading to flooding and degradation of water sources. ● Formation of new gullies. ● Denuding of forest cover ● Increase in concentration of run off causing water pollution. ● Clearing of road side vegetation for firewood, grazing, cultivation and urbanization. ● Air quality affected by vehicle exhaust and spills of toxic and hazardous chemicals from couriers using road for transportation of such materials. ● Transfer of vector diseases. ● Disturbance to flora and fauna. ● Effect on wild life through loss of habitat and encroachment.

13.5 Guidelines for Highway Projects on Environmental Issues

13.5.1 The Ministry of Environment and Forests, Government of India have outlined "Environmental Guidelines" for highway projects. The environmental parameters, associated with highway projects are given in **Table 13.2.**

Table 13.2 Environmental Parameters for Highway Projects

1.	Physiography & Terrain	14.	Surface Water Quality
2.	Geology & Seismicity	15.	Ecology & Biodiversity
3.	Hydrology and Drainage	16.	Wildlife & Habitat
4.	Erosion (Landslides, snow slides/drift, etc.)	17.	Protected Areas
5.	Agriculture	18.	Forests
6.	Land Use / Land Cover	19.	Archaeological/Historic/ Cultural/ Religious places
7.	Soil Quality	20.	Environmentally Sensitive Receptors
8.	Climate & Meteorology	21.	Fisheries and Aquaculture
9.	Ambient Air Quality	22.	Socio-economic aspects
10.	Ambient Noise Level	23.	Resettlement & Rehabilitation
11.	Vibration (Hill Roads/ Tunnel)	24.	Occupational Health & Safety
12.	Ground Water Level	25.	Road Safety
13.	Ground Water Quality	26.	Aesthetics

13.5.2 The guidelines prescribe the following procedure for Environmental Impact Assessment of Highway Projects.

a) Environmental Impact Assessment (EIA)-This is a procedure for bringing out the potential effects of human activities on environmental systems, identifying positive and negative effects resulting from the construction of projects considering various alternative sites or options and drawing out a list of parameters relevant to the project,

b) Environmental Impact Statement (EIS)-The environmental impact assessment is to be followed by Environmental Impact Statement. The basic objective of the EIS is to identify, predict and evaluate the likely impacts of a given activity and then prepare necessary action plans to eliminate or mitigate the adverse impacts as a part of the overall environment management plan. EIS should cover the following:

    i. A brief discussion of the project.
    ii. Description of the existing environment.
    iii. Likely impacts of the proposed project both adverse and beneficial; reversible, short/long term impacts.
    iv. Mitigation, protection and enhancement measures.
    v. Consideration of alternatives.
    vi. Effect of no - change alternative.

These steps are necessary to predict the likely adverse consequence which will result not only in avoidable loss of natural resources but also additional expenditure. To cite an instance, absence of catchment area treatment may lead to loss of fertile top soil, flash floods and reduction of live storage of reservoirs. The adverse consequences result in loss of national assets such as land, water, forests and a vast variety of plants and animals.

c) Environment Management Plan (EMP)

The Environment Management Plan is an implementation plan for carrying out mitigation, protection and enhancement measures as are recommended by the EIS. The EMP gives details as to how these measures should be operated, the resources required and the schedule for implementation.

13.6 Mitigation Measures

13.6.1 Keeping in view the importance of environmental aspects, it is imperative that mitigation measures are incorporated at the planning stage itself which may even involve changing the vertical and horizontal alignments. Sufficient information needs to be elicited at the planning stage in regard to environmental characteristics of the project viz. delineation of national parks, recreation areas, land use, details of forest lands, proposals for rehabilitation of displaced persons, compensation for loss of forest areas, details of land fill/embankments, proposals for protection and renewal of forests, balancing of cut & fill and site clearance etc.

13.6.2 Elevated Road infrastructure for elephant/other animals shall be as per guidelines "Eco-friendly measures to mitigate impacts of linear infrastructure on wild life" published by MOEF. A major consideration while elevating the Road infrastructure is height. The height of the pillars for elephant pass shall be at minimum 8m (thrice the height of an adult bull elephant) above ground.

13.6.3 Mitigation measures for fixed source emission could include location of all stationary equipment as far away as practicable from the work site to allow dispersion of emitted pollutants and stabilisation of areas prone to dust emission by spreading water. Mitigation measures for noise during construction could include spelling out permissible standards for noise for construction equipment in the contract specifications and restricting the hours of construction at sensitive areas such as schools and hospitals.

13.6.4 Mitigation measures for mobile sources could include performing construction activities during non-peak hours to avoid street closures, use of low emission (diesel) vehicles, setting limits of maximum allowable emission periodic checks for emission control, use of dust covers over the beds of trucks during transportation.

13.6.5 Mitigation measures for unstable hill slopes, landslide - prone areas etc. could be appropriate stabilization measures, protective/control structures and even alternate route selection etc.

13.6.6 Mitigation measures during operation phase could include construction of buffer strips on either side, planting of tree belts, construction of noise barriers, noise insulation of public building such as schools, hospitals etc., improvement of equipment and vehicle design, rerouting of heavy traffic and changing speed limits.

13.7 Environmental Impact Monitoring

Monitoring of the impacts and measures taken, especially air, noise, water, effectiveness of control measures, etc. is a requirement to ensure that the situation does not deteriorate.

13.8 Management Considerations

13.8.1 While implementing hill road projects certain aspects of construction and maintenance should be kept in mind for implementation as a part of the project covering project proposals, construction techniques, maintenance system, etc. Some important aspects are given as under:-

(i) Important points on which attention is required during planning, construction and maintenance of hill roads. —**Appendix – 13.1**

(ii) Check list of points about erosion control on the construction of roads in hilly areas. — **Appendix– 13.2**

13.9 Requirement of the Ministry of Environment & Forest and Climate Changes (MoEFCC) for Road Projects in Hilly Regions

MoEFCC has notified various Acts such as Forest (Conservation) Act 1980 (amended from time to time), Forest (Conservation) Rule 1981(amended from time to time), Environment Protection Act 1986 (amended from time to time) and Wild life (Protection) Act 1972 (amended from time to time) to mitigate the impact of development activities in the ecological fragile areas due to construction of Road Projects. Before taking of Road projects, prior clearances, as per these acts/relevant rules/guidelines, are mandatory. For detailed process involved for taking requisite clearances as per statute of MoEFCC are explained in IRC:SP:93-2017 "Guidelines on Requirements for Environmental Clearances for Road Projects" *(First Revision)*

13.9.1 *Forest Clearance*

As per Forest (Conservation) Act 1980 (amended from time to time)/relevant rule/guideline, prior approval of forest clearance is required. It involves two stages of approval- Stage I approval and subsequently Stage II approval. Once the conditions mentioned in Stage I approval are fulfilled by the User agency(Implementing agency such as NHAI, PWD/BRO/NHIDCL/Other agencies) , the user agency has to submit the requisite levies such as compensatory afforestation and NPV cost in state Compensatory Afforestation Fund Management and Planning Authority (CAMPA) funds. Once these funds are released, the State Forest Officer authorised by State Govt. not below the rank of DFO will issue order for felling of trees and the order should be put on Public Domain by State Govt as well as user agency by hosting on their respective websites to enable public to file objection on the order. Once the felling of trees will be completed, the State Forest Dept authorised by the State Govt, officer not below the rank of DFO, will issue order for commencement of work which should be put on the Public Domain by State Govt and user agency by hosting on their websites to enable public to file objection on the order. It is mandatory requirement as per order of Hon'ble NGT to put these two orders in public domain/website. Stage II approval is pre-requisite for diversion of forest land to Road Authority.

13.9.1.1 Steps involved in seeking Forest Clearance

(i) Registration of user agency (Implementing agency such as NHAI, PWD/BRO/NHIDCL/Other agencies) on MoEFCC website https://parivesh.nic.in to get login credentials.

(ii) Submission of project details along with all requisite documents in relevant formats [Part I of Form A/B/C depending upon project type] on this website.

(iii) Nodal Officer (designated State Forest Deptt Officer authorized by State Govt) will scrutinize the proposal and send to Divisional Forest Officer (DFO)/District Collector (DC) online for necessary action.

(iv) DFO will upload the Part II of Form A/B/C along with his/her recommendations and site inspection report on the portal and forward the same to CF/CCF for necessary action.

(v) DC will upload NOC under Forest Right Act.

(vi) Conservator of Forest (CF)/ Chief Conservator of Forest(CCF) will upload the part III of Form A along with his/her recommendation and site inspection report (if site inspection done) and forward the same to Nodal Officer online for necessary action.

(vii) Nodal Officer will upload part IV of Form A on portal along with his/her recommendation & site inspection report (if site inspection done) and forward the same online to Secretary(Forest) of the State Govt.

(viii) Secretary (Forest) of State Govt. will upload his/her recommendation on portal and the same is forwarded online to Regional Office(RO) of MoEFCC.

(ix) Depending upon the area of the forest land to be diverted, the stage I approval will be recommended by MoEFCC & CC/Regional Empowered Committee (REC) of MoEFCC for Stage I approval by MoEFCC(HQ).

(x) After Stage I approval, MoEFCC (HQ) will upload the same on the portal.

(xi) After compliance of conditions mentioned in the Stage I approval, the Stage II approval is granted by MoEFCC.

13.9.2 *Environment Clearance (EC)*

As per Environment (Protection) Act, 1986 (amended from time to time)/EIA notification issued on 14th September 2006 and subsequent amendments, EC is required for new national highways and expansion of existing highways. The process of obtaining environmental clearance for road projects has been described in EIA Notification 2006, as amended from time to time. The applicability of Environment Clearance for highways projects is given under the SCHEDULE appended to the EIA Notification 2006. The relevant extract of the latest provision in relation to highway development projects is quoted below:

Table 13.3 Relevant Extract of Latest Provision in relation to Highway Development Projects

Project or Activity		**Category with threshold limit**		**Conditions if any**
		A	B	
(1)	(2)	(3)	(4)	(5)
7(f)	Highways	i) *New National High ways; and* ii) *Expansion of National Highways greater than 100 km involving additional right of way or land acquisition greater than 40m on existing alignments and 60m on re-alignments or by-passes*	i) *All New State Highway Projects* ii) *State Highway Expansion projects in Hilly terrain (above 1,000 m MSL) and or Ecologically Sensitive Areas.*	General Condition shall apply Note: i) Highways include expressways MoEFCC Circular dated 14th July 2022 [S.O. 3194(E)] ii) *All Highway projects are exempted upto 100 km from line of control or border subject to compliance of Standard Operating Procedure notified in this regard from time to time* iii) *Width at toll plaza and junction improvement at intersection of other roads is exempted from Right of Way*

Any project or activity specified in Category 'B' will be appraised at the Central level as Category 'A', if located in whole or in part within 5 km from the boundary of: (i) Protected Areas notified under the Wild Life (Protection) Act, 1972 (53 of 1972); (ii) Critically Polluted areas as identified by the Central Pollution Control Board constituted under the Water (Prevention and Control of Pollution) Act, 1974 (6 of 1974) from time to time; (iii) Eco-sensitive areas as notified under sub-section (2) section 3 of the Environment (Protection) Act, 1986; and (iv) Inter-State boundaries and international boundaries

13.9.2.1 Steps involved in Environment Clearance

(i) Registration of user agency (Implementing agency such as NHAI, PWD/BRO/NHIDCL/Other agencies) on MoEFCC website http://parivesh.nic.in to get login credential.

(ii) User agency will upload project details along with required documents of TOR in Form I (Part I)/EC application.

(iii) Member Secretary will consider the proposal of TOR/EC application (within 5 working days/20 days respectively).

(iv) Once the Member Secretary accepts the proposal, it will be put up before EAC for consideration.

(v) Subsequently, it will be approved by Competent Authority of MoEFCC.

13.9.3 *Wild Life Clearance*

As per Wild Life (Protection) Act 1972 (amended from time to time), wild life clearance is to be taken when the project NH passes through Eco sensitive/protected area notified by MoEFCC.

13.9.3.1 Steps involved in Wild life Clearance

(i) Registration of user agency (Implementing agency (such as NHAI, PWD/BRO/NHIDCL/Other agencies) on MoEFCC website http://parivesh.nic.in to login credential.

(ii) If both forest clearance and wildlife clearance are required, forest clearance application has to be submitted first.

(iii) Proposal will be submitted by the user agency on the website of MoEFCC.

(iv) DFO will upload the Part II of Form (A) on portal along with his/her recommendation & site inspection report and forward it to Chief Wildlife Warden (CWW).

(v) Chief Wildlife Warden (CWW) will upload his/her recommendation and site inspection report (if inspection is done) and forward to State Govt.

(vi) State Govt. (Secretary- Forest) will upload the recommendation of State Board of Wild Life (SBWL) along with recommendations of State Govt on the portal.

(vii) Proposal will then be forwarded to MoEFCC, Head Office (Wild Life), New Delhi.

(viii) MoEFCC (HQ) Wild Life Division will process the proposal for approval of competent authority of MoEFCC.

(ix) After taking approval of competent authority, recommendation letter of National Board of Wild Life (NBWL) is uploaded on the portal.

13.10 Muck Disposal Site

Huge quantity of muck is generated in construction and widening of roads/tunnels in Hills. At the time of applying for stage I approval for Forest Clearance, site of muck disposal shall be included in the Forest Clearance application so that at the time of commencement of project, the spot is ready for muck disposal. Efforts should be made to utilize the muck generated to extent possible and the remaining muck needs to be disposed of in proper manner as per Forest Clearance Stage I approval under supervision of the State Forest Department. Efforts should be to prevent felling of muck in the stream/river by construction of retaining structure around muck disposal site of adequate strength having proper filter medium.

13.10.1 *Some important aspects of muck disposal site*

(i) Proper estimation of muck generation during construction after taking into account the muck to be used in construction work at DPR stage.

(ii) Allocation/identification of muck disposal site of adequate size and numbers at DPR stage.

(iii) Effort should be to allocate muck disposal sites near to the construction/hill cutting site and sufficient no of muck disposal sites to avoid tendency of contractor to dump muck in valley/river side.

(iv) Provision of retaining structure for muck disposal site to contain the muck in site to avoid falling in river /stream at DPR stage. The top level of retaining structure shall be kept atleast 1.00 mtr. to 1.50 mtr. higher than the top of the muck surface.

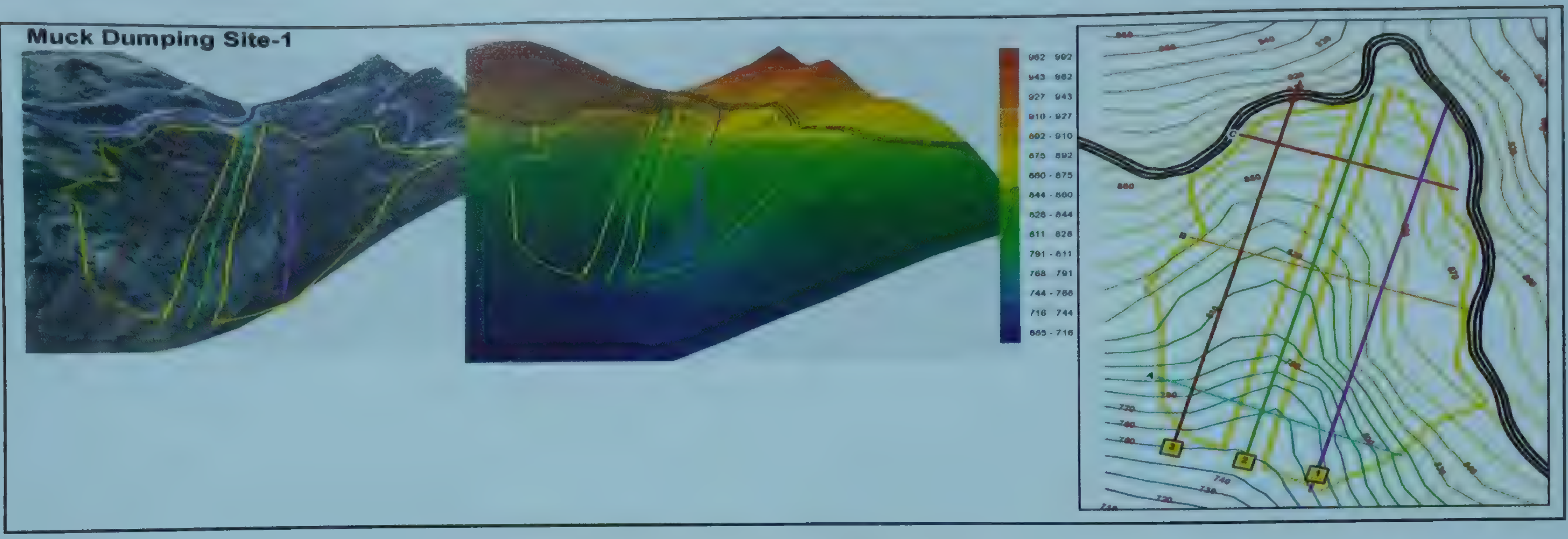
(v) Details of muck disposal site (size/location) to be specified in contract agreement.

(vi) Provision of retaining structure to retain muck in the muck disposal site should be mentioned in the Contract Agreement. [for example. under Schedule-B in respect of EPC/PPP contract documents]

(vii) Cost of the retaining structure for muck disposal should be inbuilt in the contract price.

(viii) The contractor may be asked to submit photograph of muck disposal site with every bill to ensure proper muck disposal.

(ix) Digital elevation models may be prepared for all muck dumping sites to ascertain the topography and determining the location, length & height of the gabion wall for slope protection so as to prevent the muck from reaching into natural streams. A sketch showing muck disposal site is at **Fig, 13.1**


Muck Dumping Site-1
962 - 992
943 - 962
927 - 943
910 - 927
892 - 910
875 - 892
860 - 875
844 - 860
828 - 844
811 - 828
791 - 811
768 - 791
744 - 768
716 - 744
685 - 716

Digital Contour Mapping

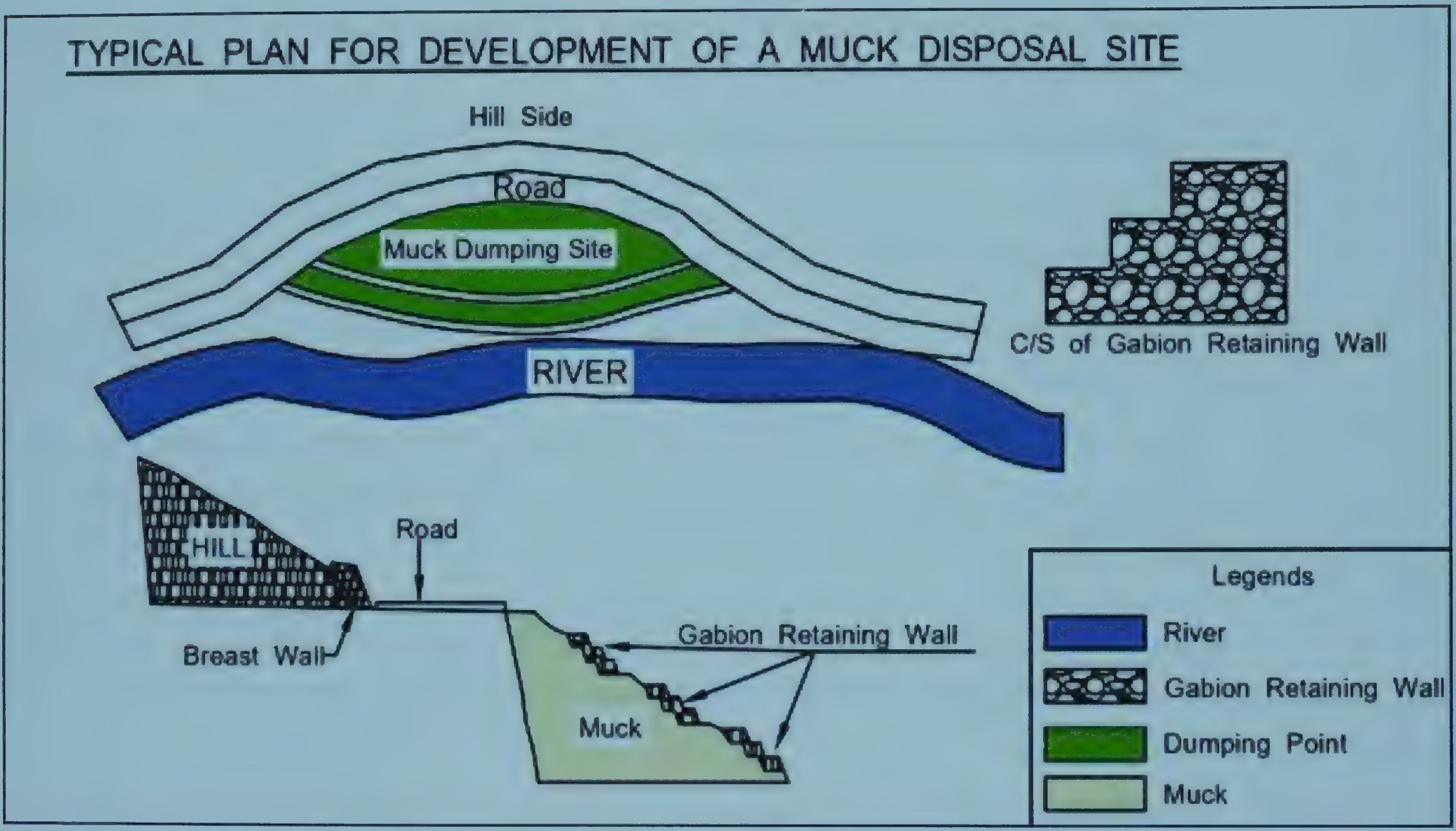

TYPICAL PLAN FOR DEVELOPMENT OF A MUCK DISPOSAL SITE
Hill Side
Road
Muck Dumping Site
RIVER
C/S of Gabion Retaining Wall
HILL
Road
Breast Wall
Gabion Retaining Wall
Muck
Legends
River
Gabion Retaining Wall
Dumping Point
Muck

Fig. 13.1 Sketch of Muck Disposal Site

13.11 Conclusion

As explained above, the requisite clearances, as per the relevant Acts have become an inescapable part of preparation of DPR, during execution and operation of road projects in Hill roads. Further, even if Forest clearance, Environment clearance , Wild Life clearance and other requisite clearance are not required as per provisions of relevant Acts/Rule, it is advisable to inbuilt mitigation measures in these projects, as required and imposed in the approval of clearance by the Forest Deptt/MoEFCC. It is suggested that even if Environment Clearance is not required, Environment Impact Assessment (EIA) and Environment Mitigation Plan (EMP), as per standard TOR of MoEFCC, may be prepared at DPR, alignment may be selected and mitigation plan may be inbuilt in project cost. Guidelines published by MoEFCC on Eco Friendly measures to mitigate impact of linear infrastructure on wildlife should be adopted even when no wildlife clearance is required/the project road does not lie in protected area. Requisite clearances, as per Acts, need to be taken prior to commencement of work and their conditions must be followed in letter & spirit failing which there may damage the fragile ecosystem of hills and litigation in Hon'ble NGT/Hon'ble Court/penalty by Forest Deptt. The MoEFCC issues circular & guidelines/ revise their circular & guide lines from time to time and the same are uploaded on its web site http://parivesh.nic.in

Appendix - 2.1

(Para 2.10.5.2)

CONSTRUCTION METHODOLOGY FOR PRECAST SEGMENTAL BOX CULVERTS

1. General

The construction of Precast Box Culverts comprises of the casting and installation of RCC Box Segments inclusive of catch water pit & outfall of discharge to avoid scour in valley portion.

Workmanship is an essential activity complying with the clause 1504.2, 1504.4 & MoRTH specification. Formwork shall be made so as to produce a finish concrete true to shape, line levels and dimension as shown in the drawing subject to the tolerances specified in respective section of these specifications. Subsoil condition shall also be taken into account while designing the staging to avoid discrepancies etc.

2. Reinforcement

Bar bending schedule shall be prepared and submitted to get Engineer's approval before stars of work. Bar schedule shall include number, shape and cutting length of bar and weight with respect to each type. A separate bar bending schedule shall be prepared for auxiliary items like spacer, chairs etc.

3. Protection and Curing

Exposed surfaces of concrete shall be kept continuously in a damp or wet condition by ponding or by covering with a wet layer of sacks, canvas, Hessian or similar materials and shall be kept continuously wet for a period of minimum 14 days from the date of placing of concrete.

4. Work Safety

4.1 During construction of culverts or minor bridge box, diversion road is to be built if required to pass ongoing vehicles with adequate safety. Before the diversion of road starts, retro-reflective traffic signs shall be installed adjacent to the road shoulders to protect the ongoing work and workers.

4.2 During the night time, there should be lights on the construction location so that night time drivers will be alert while driving.

4.3 No machine or equipment shall be allowed to remain or the existing road or shoulder unattended at any time unless it is properly protected & secured in safe manner.

4.4 The safety officer shall make frequent patrols along the highway to ensure the safety equipment & signs are operational at all time.

5. Quality Control

Random sampling lot by lot shall be made. Acceptance criteria for the 7 & 28 days cube strength to be followed. Concrete for making numbers of cubes shall be taken from a batch of concrete at a point of delivery according to procedures laid down in IS:1199.

6. Site Record

The site engineers shall ensure that the site supervisors continuously supervise and observe the constructions of the culvert and maintain the daily site dairy sheet.

7. Materials

(i) Box segment shall be casted as per the approved drawings with concrete of minimum grade of M-30 for Box culverts, TMT-Fe500D steel. Other RCC works like cut-off wall, head wall etc. shall be casted with concrete of minimum grade of M-25.

(ii) A ratio of 1:2 Cement mortar for jointing of box segments.

(iii) Duly tested admixture/additives conforming to IS 6925 and IS 9103 (without replacement of cement) may be used.

(iv) Reinforcement shall be Thermo-Mechanically Treated (TMT) deformed bars of grade Fe500D conforming to IS code 1786. Only uncoated steel shall be used as per shape and size shown on the drawing.

(v) Size of coarse aggregate shall be referred with the technical specification table No.1700-7 of MoRT&H.

8. Equipment

(i) Concrete batching (automatic) plant of minimum capacity 30 cum/hr.

(ii) 25 T Crane and bucket system for placing of concrete.

(iii) Transit truck mixer.

(iv) Needle vibrators (Electrical or petrol drive units).

(v) 25 T Crane for handling shuttering, reinforcement cage and other materials.

(vi) Suitable capacity crane for box segment erection.

9. Setting out

Before start of work, a proper diversion should be provided for smooth flow of traffic as directed by Engineer. In case space for diversion is not available then erection shall be started in first half and then continued for another half. Smooth flow of traffic must be maintained.

10. Formwork

All materials for formwork shall comply with the requirements of IRC:87. Only steel formwork shall be used. All bolts shall be countersunk. The approved internal ties or plastic spacer shall be used. Structural steel tubes used as support for forms shall have a minimum wall thickness of 4 mm.

11. Design of Formwork

Complete design and drawing of formwork for box type structure shall be submitted for approval before start of work. The design of formwork shall conform to the IRC:87.

12. Construction Steps

(i) Layout should be set and co-ordinates shall be checked properly.

(ii) 2.00 m length of 1.5 m x 1.5 m, 2.0 m x 2.0 m,1.5 m x 2.0 m etc, box segments shall be casted in casting yard. With suitable cranes for fixing and de-shuttering of the box molds, reinforcement cage placement and concrete pouring shall be carried out.

(iii) The casted Box segments shall be shifted/transported by suitable means to the required site location where PCC already laid, once the curing period is completed.

(iv) The shifted segment shall be paced/fixed in a systematic manner with proper interlocking of each segment on a well prepared PCC bed starting from D/S to U/S with the help of Crane of suitable capacity. Anchoring of Box Segment at its bottom to be done to avoid sliding due to heavy flow during monsoon.

(v) Layout should be set and co-ordinates be checked properly.

(vi) Excavate the retaining wall and Box portion 300 m above the founding level and balance shall be trimmed to avoid over excavation.

(vii) After placing/fixing the segments, the jointing space between the segment shall be filled carefully with 1:2 cement mortar mixed sufficiently dry to remain in position when forced with a trowel or rammer. Care shall be taken to fill all voids and excess mortar shall be removed.

13. Placing of Reinforcement

Reinforcement shall be placed in accordance with drawing and get inspected and approved by Engineer. Immediately after approval, pouring of concrete shall follow.

Reinforcement shall be tied with binding wires in such a way that it shouldn't be displaced while pouring the concrete on it.

Cover block shall be made of cement mortar with same durability like surrounding concrete.

Layers of bars shall be separated by spacer bars kept at approximately 1 m interval and minimum size of spacer bar shall be 12 mm, or equal to maximum size of main reinforcement or maximum size of aggregate whichever is greater, Horizontal reinforcement shall not be allowed to sag between supports.

Necessary auxiliary bars like spacer, chairs, and blocks shall be provided to fix reinforcement in position.

14. Pre-cast Concrete Box Culverts have several advantages over Cast in Situ Materials.

(a) Superior Strength and Durability: The strength of pre-cast concrete gradually increases over time. Other materials can deteriorate, experience greater creep and stress relaxation, lose strength and/or deflect over time. The load carrying capacity of pre-cast concrete is derived from its own structural qualities and does not rely on the strength or quality of the surrounding backfill materials. Properly designed pre-cast concrete box culverts can easily support vehicular, aircraft and railway loads meeting AASHTO, FAA and AREMA specifications.

(b) Quality Control: Because pre-cast concrete products are produced in a controlled environment, they exhibit high quality and uniformity. Typical factors affecting quality, found on a job site like temperature, improper curing, poor craftsmanship and material quality are nearly eliminated in a plant environment. Pre-cast concrete products produced in a quality controlled environment and installed with high quality sealants offer a superior solution to water tightness requirements. Standard watertight sealants are specially formulated to adhere to pre-cast concrete, making watertight multiple seam pre-cast concrete box culverts possible.

(c) Availability and Case of Installation: Because Pre-cast concrete box culverts are manufactured well in advance of installation, they are ready for transportation to the job site at a moment's notice. They are quickly installed in a matter of hours using a crane and a small crew. Backfilling can begin immediately rather than waiting several days or more for cast in situ concrete to gain proper strength. Once backfilled, road construction can begin, greatly reducing the deviation of any associated lanes and congestion in the surrounding communities.

(d) Reduced Weather Dependency: Pre-cast concrete increase efficiency because weather will not delay the manufacturing process in the pre-cast plant. In addition, weather conditions at the job site do not significantly affect the schedule. Conversely, forming and placing of concrete for cast-in-place applications can be delayed significantly due to poor weather conditions.

(e) Aesthetically Pleasing: Pre-cast concrete box culverts can also include spandrel and wing wall panels with multitude of architectural finishes. Finishes commonly available are: steel form, textured form lines, exposed aggregate, acid etched, brick and sand blast. Each is distinctly different, providing specifiers and owners a broad choice in appearance. Architectural finish compliment the surrounding environment as well as comply with local aesthetic requirements.

(f) Environmentally friendly: Pre-cast concrete is nontoxic, environmentally safe and made form all natural materials, making it an ideal material for use below grade or for the conveyance of water. Concrete has no proven ill effects on groundwater and surface water quality helping to preserve our natural water resources.

(g) Economical: By incorporating pre-cast concrete box culverts in a project, finishing work under budget can be ensured. Fewer skilled laborers and overall man-hours will be required for the project, making pre-cast concrete box culverts ideal for meeting the needs of today's fast placed construction projects.

(h) Avoidance of Diversion: Traffic can be allowed to move on the partly laid segments. Hence no traffic will be stopped during construction.

15. Relevant Codes:

(i) IRC:122 "Guidelines for Construction of Pre-cast Concrete Segmental Box Culverts" .

(ii) IRC:6 Standards Specifications and Code of Practice for Road Bridges, Section-II “Loads and Load Combinations”

(iii) IRC:SP:13 "Guidelines for the Design of Small Bridges and Culverts".

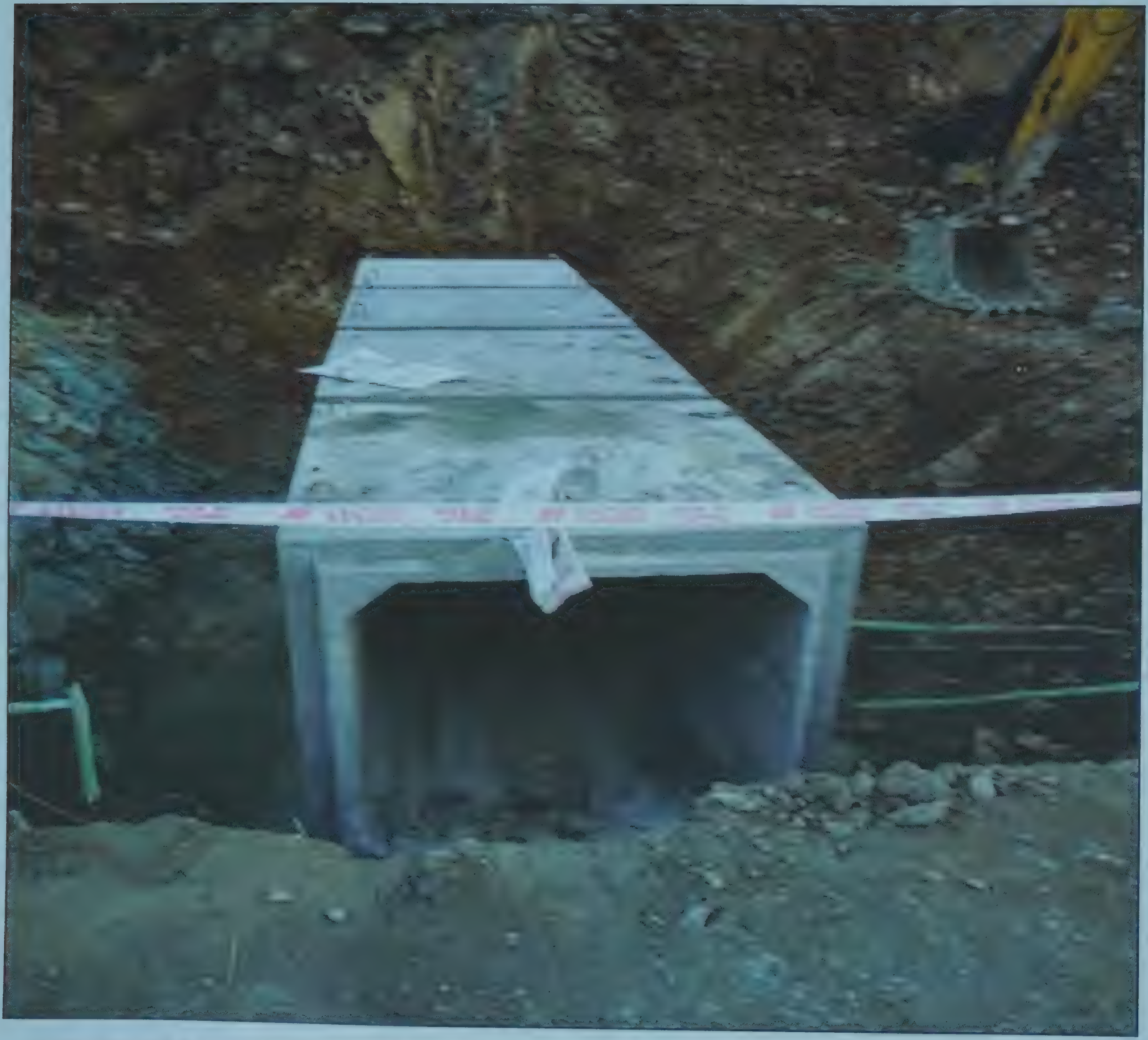


Fig. 2.1 (A) Laying of Precast Box Segments at one of the sites of Chardham Project

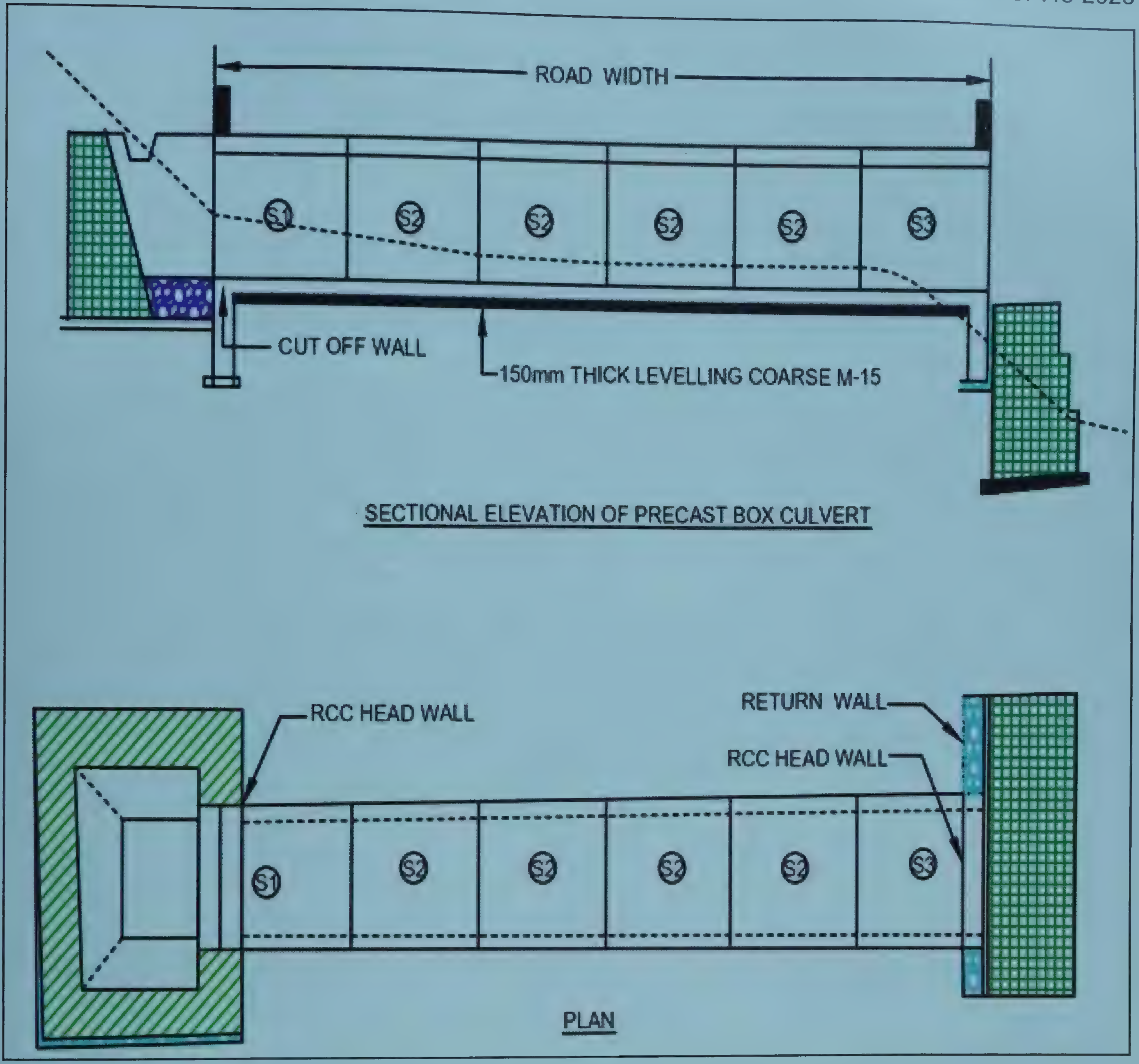

ROAD WIDTH
S1
S2
S2
S2
S2
S3
CUT OFF WALL
150mm THICK LEVELLING COARSE M-15
SECTIONAL ELEVATION OF PRECAST BOX CULVERT
RCC HEAD WALL
RETURN WALL
RCC HEAD WALL
S1
S2
S2
S2
S2
S3
PLAN

Fig. 2.1 (B) Typical Plan, Elevation of Segmental Box Culvert

Appendix - 2.2

(Para 2.11)

PROVISION OF UTILITY (O.F.C) DUCT IN HILL ROADS

1. Introduction

In the present age of advancement of information technology, use of internet has been increasing exponentially. In this background, in order to promote Digital India program, it is the aim of Govt to provide internet connectivity even in the remotest corner of India. Importance of internet connectivity is more in hilly region due to inadequacy of physical transport such as road, railways and air connectivity.

1.1. It has been observed that optical fiber cables are generally laid on hill side after cutting the toe of hills. Different Telecom Operators lay their OF cables at different time depending upon launch of their services in that area, damaging the hill toe/road frequently. This problem is more serious when the hill road is developed with Breast wall & Pucca drains with huge construction cost as cutting for laying OFC, damage these structures causing destabilization of hill slopes and choking the drains frequently.

1.2. In the above background, it is suggested to provide OFC duct in all hill road projects being developed with breast wall/retaining, hill slope stabilized with drapery system, nailing, netting, anchoring, hydro-seeding and Pucca side drains. Provision of Cable ducts will avoid damage to these structures constructed at substantially high construction cost. Typical cross section showing location of Cable duct is at **Fig.2.2(A)**

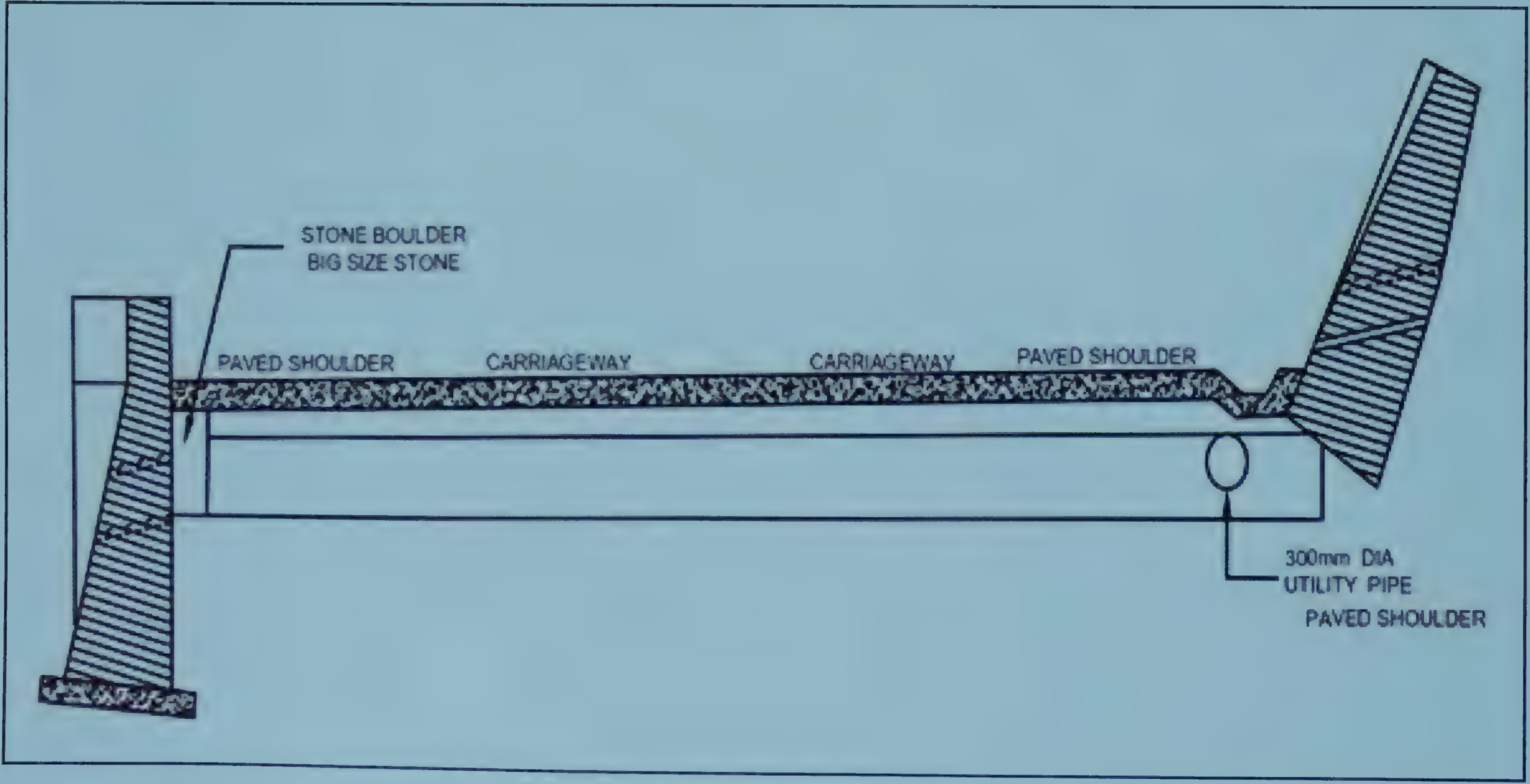


Fig.2.2 (A) Two Lane in open area with both side Protection

2. Following factors may be taken into account during providing optical fiber cable ducts:

(a) The Cable ducts of single vent (HDPE pipe/ concrete Hume pipe) of 300 mm or depending upon the present requirement and potential of future expansion of internet connectivity in the concerned area of road constructions may be provided on hill sides. This will accommodate all the cables of different Telecom Operators.

(b) As different Telecom Operators will not lay their OF cables at a time, the Operators laying their OF cable subsequently, should lay their cables more carefully to avoid damage/dislocation of already laid OF cables. Alternatively, OF Cable ducts of small diameters (40-60 mm) grouped together (5 to 10 no. of ducts), depending upon present requirement and potential of future expansion of internet connectivity in the location maybe laid. Each small OF Cable duct will be for a different Telecom Operator.

(c) Selection of single vent OF cable duct and multiple of cable ducts depends upon the site condition, cost of laying of cable duct, potential of future of expansion of internet connectivity in the location etc. Telecom Operations may also be consulted in this regard.

(d) Further, in order to lay the OF cable and for inspection/maintenance of the joint of Cable during the operation period, chambers are to be provided at certain intervals as per the guidelines of the Dept. of Telecommunication, Govt. of India/BSNL. Sketch showing typical dimension of chambers is at **Fig.2.2(B)**

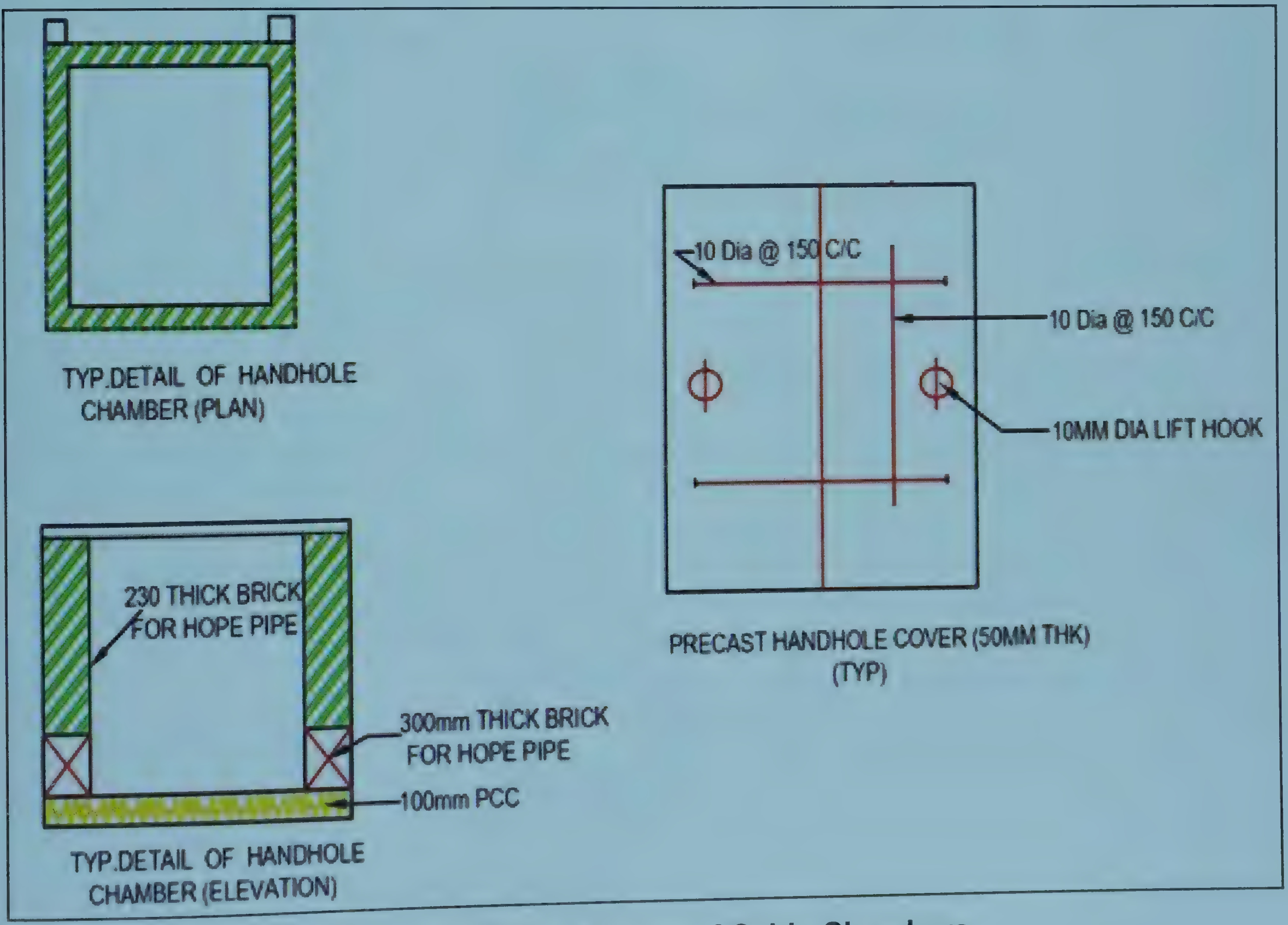

TYP.DETAIL OF HANDHOLE CHAMBER (PLAN)
230 THICK BRICK FOR HOPE PIPE
300mm THICK BRICK FOR HOPE PIPE
100mm PCC
TYP.DETAIL OF HANDHOLE CHAMBER (ELEVATION)
10 Dia @ 150 C/C
10 Dia @ 150 C/C
10MM DIA LIFT HOOK
PRECAST HANDHOLE COVER (50MM THK) (TYP)

Fig. 2.2(B) Type Section of Cable Chambers

(e) In the built up area/inhabited area, the OF cable ducts should be provided on both side of the road so that OF cable connectivity will be provided easily to the abutting houses/establishments. Further, where the Roads are to be constructed/widened having both sides protection with breast wall/retaining walls or passing through Built up section with abutting structures, the cables ducts may be provided below the paved/hard shoulder as shown in **Fig. 2.2(C)**

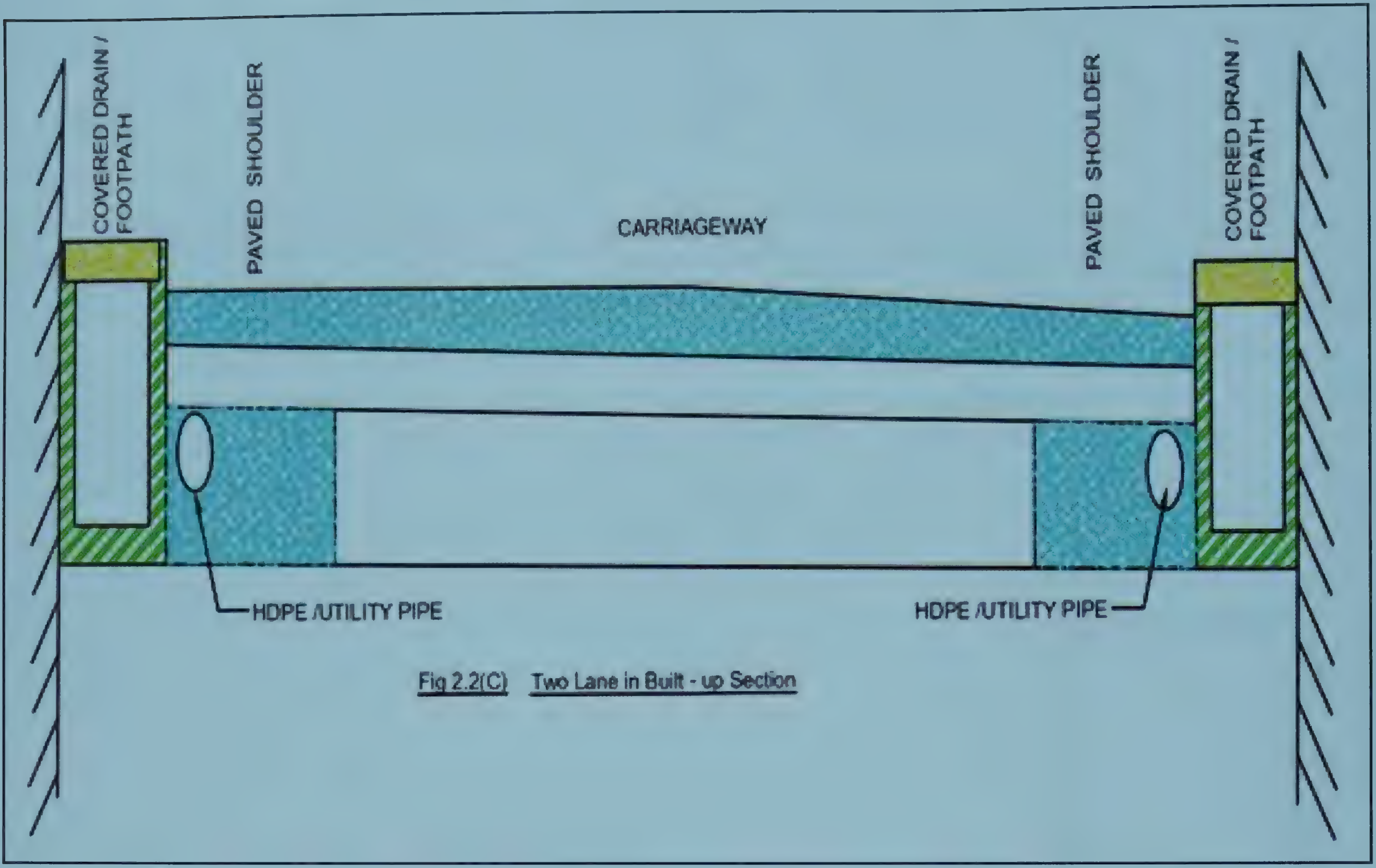

COVERED DRAIN / FOOTPATH
PAVED SHOULDER
CARRIAGEWAY
PAVED SHOULDER
COVERED DRAIN / FOOTPATH
HDPE /UTILITY PIPE
HDPE /UTILITY PIPE
Fig 2.2(C) Two Lane in Built - up Section

Fig. 2.2 (C) Two Lane in Built –up Section

(f) The cable ducts should cross the culverts, minor and major bridges without disturbing the active flow cross section and destabilizing the safety of the structure. It should be anchored below the deck bottom of culverts/solid Plate Bridge with proper attachment. However, in case of other type of bridges, it should be anchored at suitable location outface of flange in box Type Bridge and below the overhang of the footpath in case of girder bridges. Sketch showing crossing of cable ducts over culvert and bridges of different type of superstructure are enclosed at **Fig. 2.2(D1,D2)/2.2(E).**

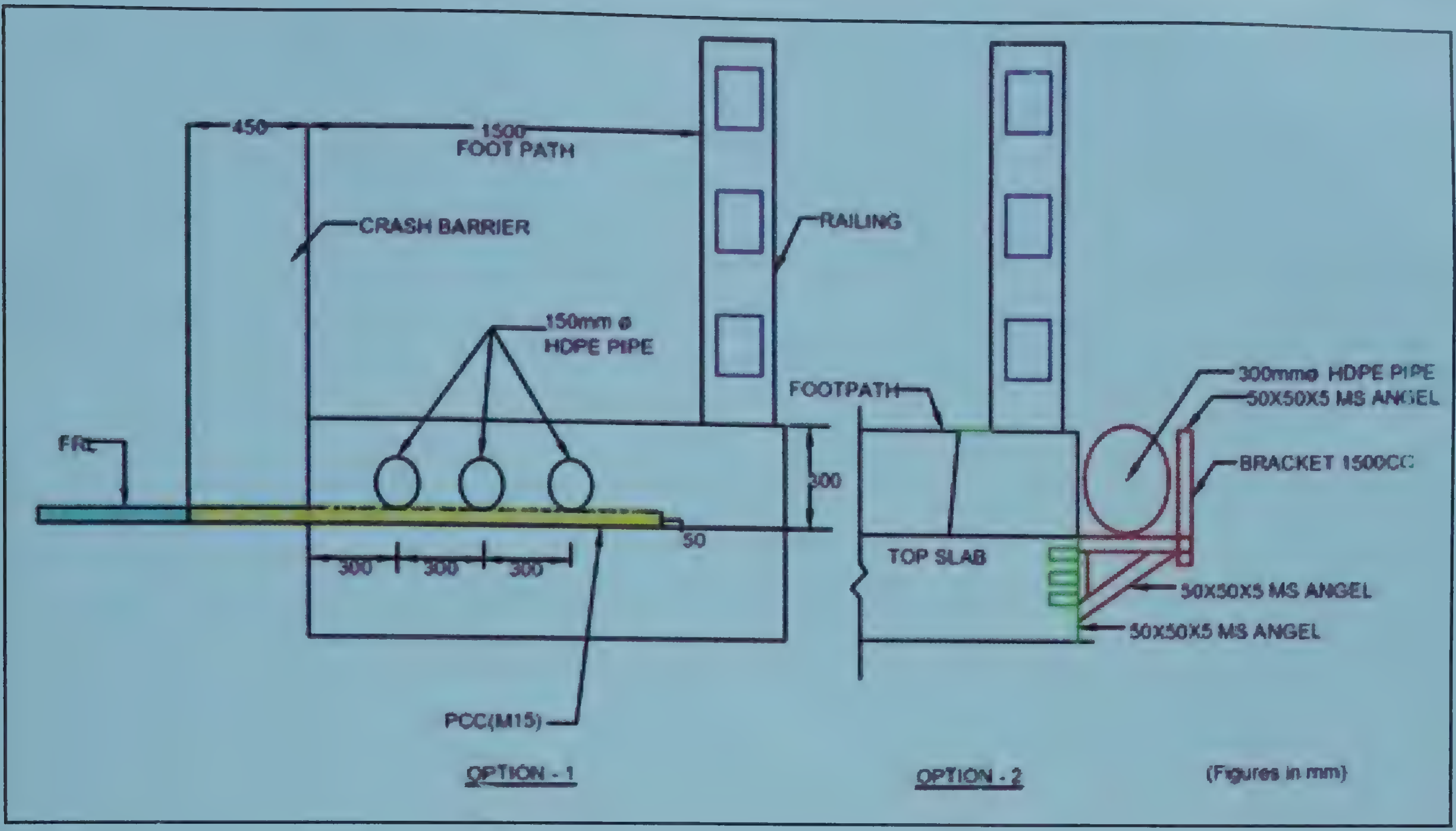
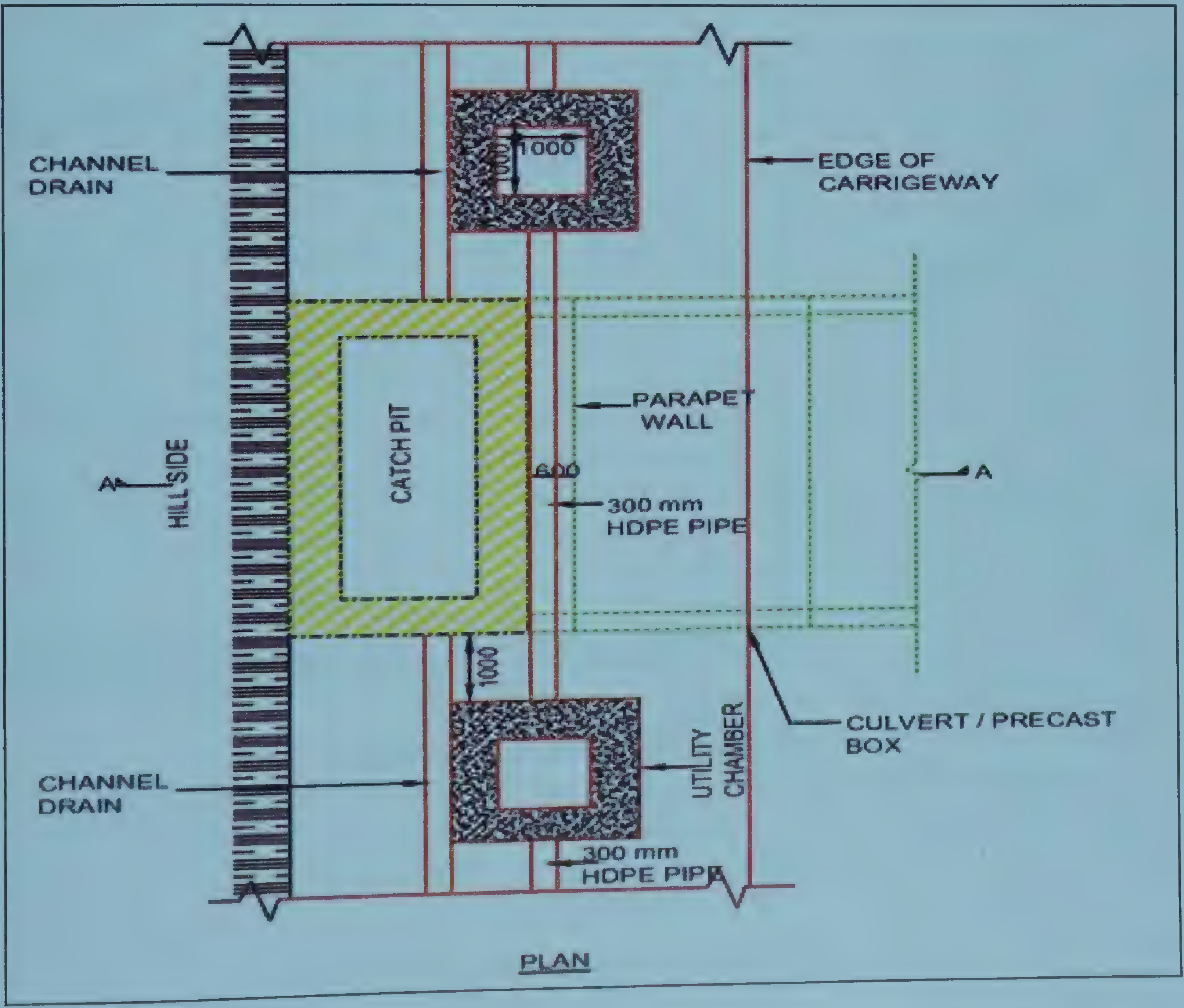
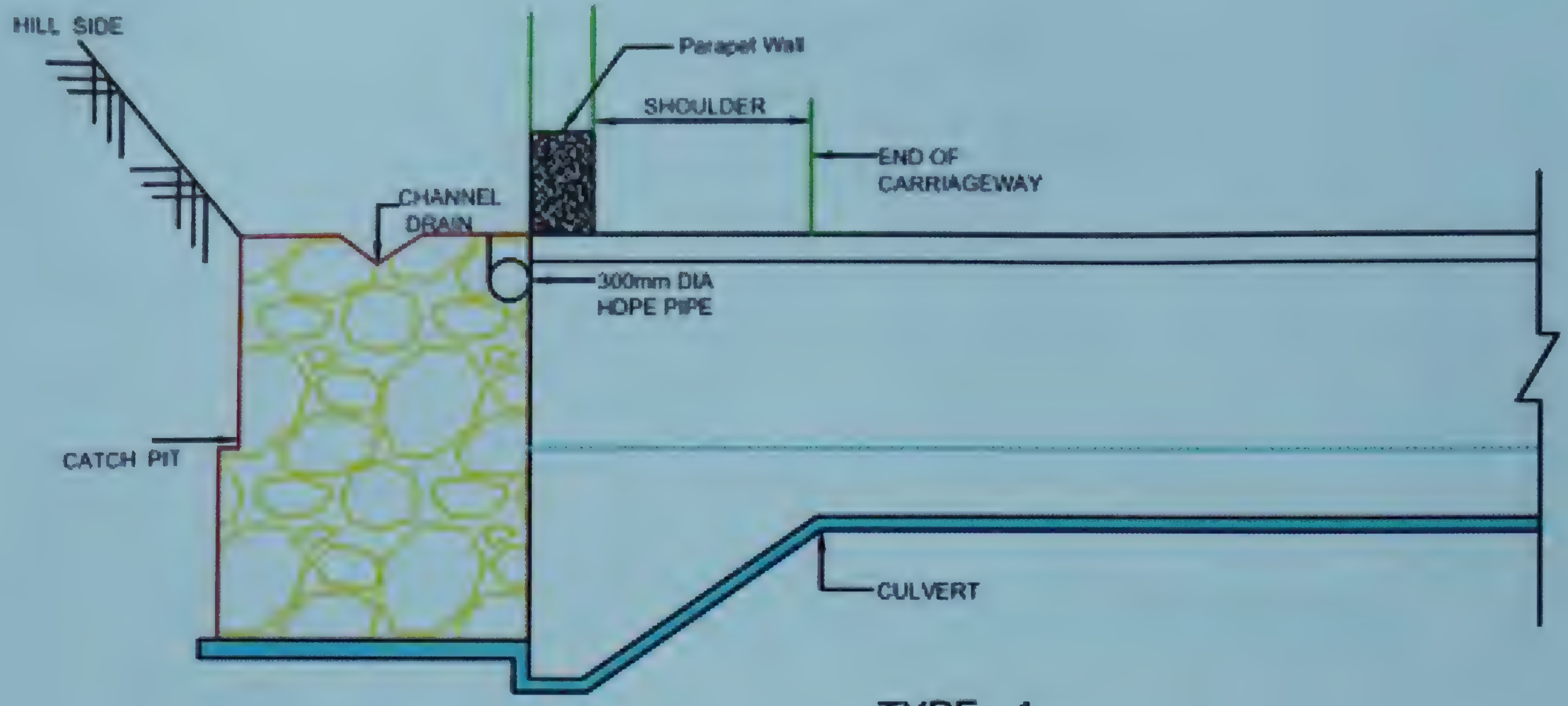
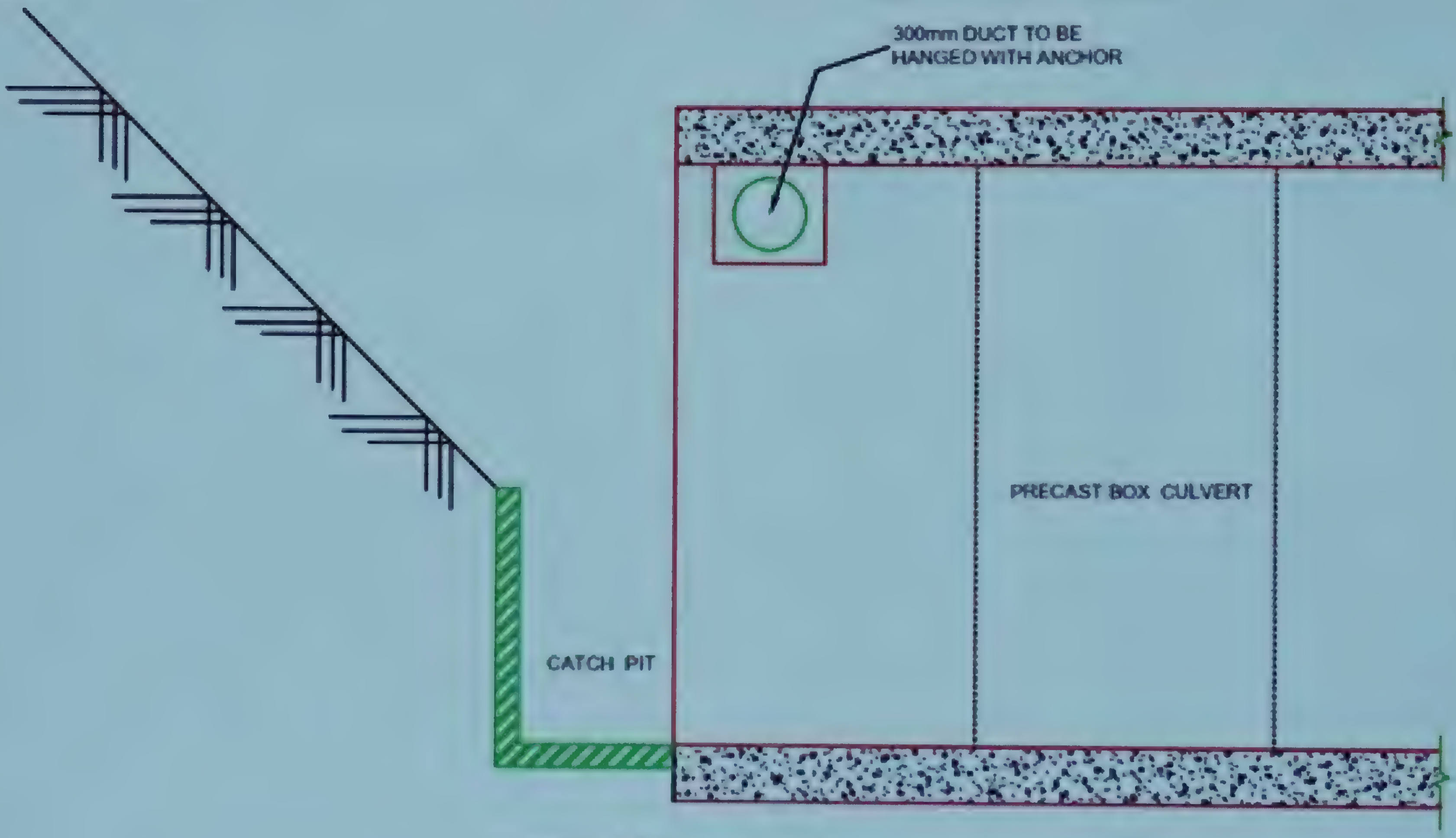

450
1500
FOOT PATH
CRASH BARRIER
RAILING
150mm ø
HDPE PIPE
FOOTPATH
300mmø HDPE PIPE
50X50X5 MS ANGEL
BRACKET 1500CC
FRL
300
50
300
300
300
TOP SLAB
50X50X5 MS ANGEL
50X50X5 MS ANGEL
PCC(M15)
OPTION - 1
OPTION - 2
(Figures in mm)

Fig. 2.2 (D1) Typical Section for Duct Crossing the Bridge Structures


1000
1000
CHANNEL
DRAIN
EDGE OF
CARRIGEWAY
CATCH PIT
PARAPET
WALL
A
HILL SIDE
600
300 mm
HDPE PIPE
A
1000
UTILITY
CHAMBER
CULVERT / PRECAST
BOX
CHANNEL
DRAIN
300 mm
HDPE PIPE
PLAN


HILL SIDE
Parapet Wall
SHOULDER
END OF CARRIAGEWAY
CHANNEL DRAIN
300mm DIA HDPE PIPE
CATCH PIT
CULVERT

TYPE - 1
FIG 2.2 (D2)


300mm DUCT TO BE HANGED WITH ANCHOR
PRECAST BOX CULVERT
CATCH PIT

TYPICAL SECTION FOR TYPE -II
(A HOLE TO BE LEFT IN BOX SEGMENT FOR DUCT)

TYPE-2

SECTION A-A

Fig. 2.2(D2) Typical Location of Cable Duct

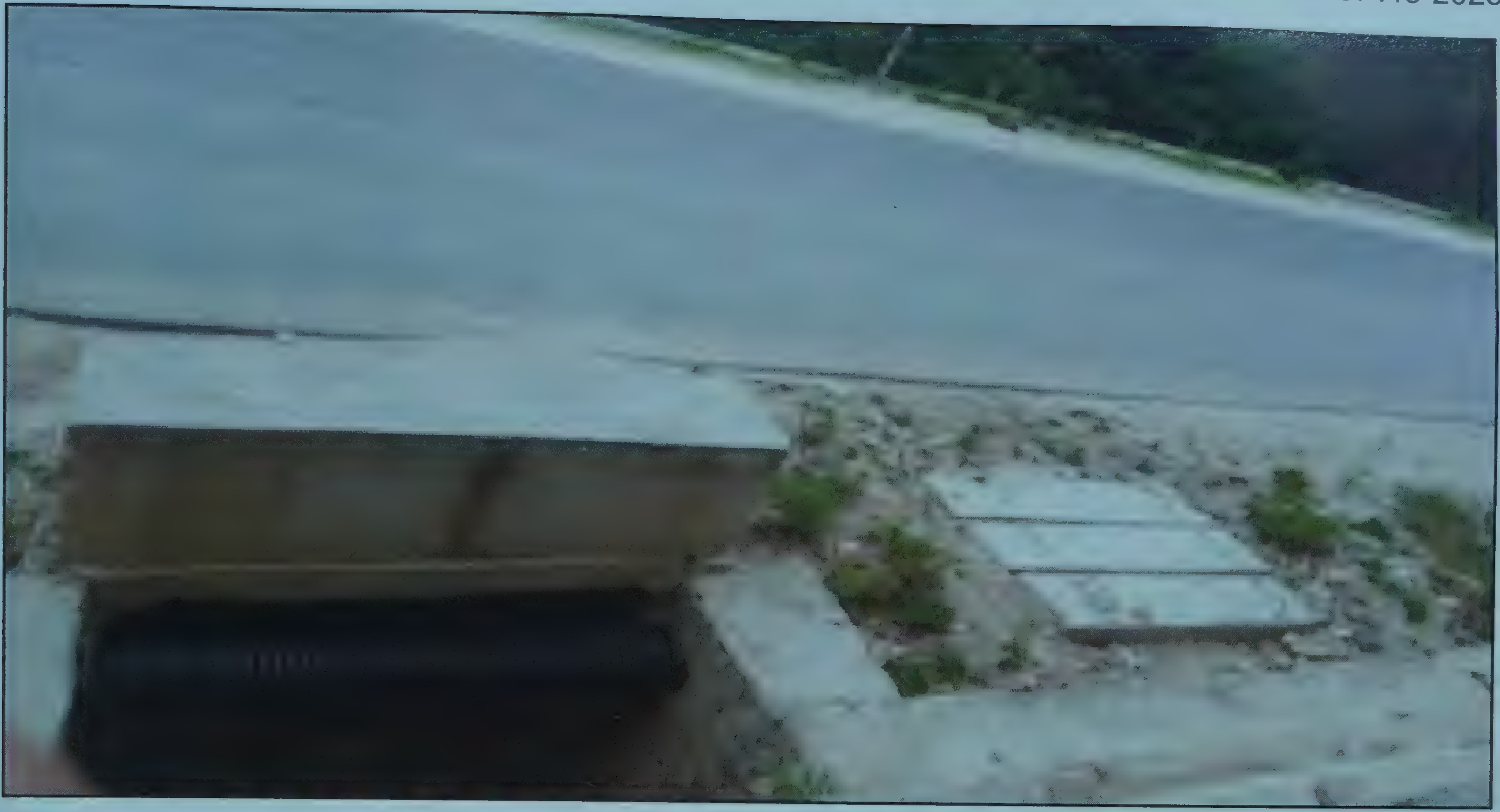


Fig. 2.2 (E) Typical Section of Cable Duct from one of the Sites of Chardham Project

(g) The laying of utility duct may be done on hill side in Hilly terrain. In habited area crossing of utility duct is done at two or three places to avoid any excavation in project road to cross the utilities. At hair pin bends, the crossing of utility duct might be necessary to bring the duct on hill side. To accommodate the HDPE pipe 0.6 m wide and 1.5 m deep trench may be excavated at desired places. The inner edge of trench may be located at 5 m from the proposed center line of pavement. The soil base of trench may be compacted and a layer of sand may be laid over it. The jointing of 20ft HDPE pipe may be done with coupler and gasket arrangement. To cross the utility duct at precast culvert specially designed chamber may be constructed at both ends of culvert. The chamber may contain two compartments, one rectangular and one circular. The maximum depth of these circular compartment may be 2 m from the top and approximately 1.5 m from FRL of road and the depth of rectangular compartment may be 1 m approx. The rectangular compartment may accommodate the incoming duct at bottom and the circular compartment may accommodate the outgoing duct on top at one side of culvert or other side of culvert. The circular compartment accommodates incoming duct and rectangular compartment accommodate outgoing duct at bottom. The duct may cross the culvert from catch pit and adjacent and parallel to parapet of culvert. To protect the exposed pipe over the catch pit encasing of pipe may be done with cement sand mortar and wire mesh. A typical section is shown in **Fig. 2.2(F)**

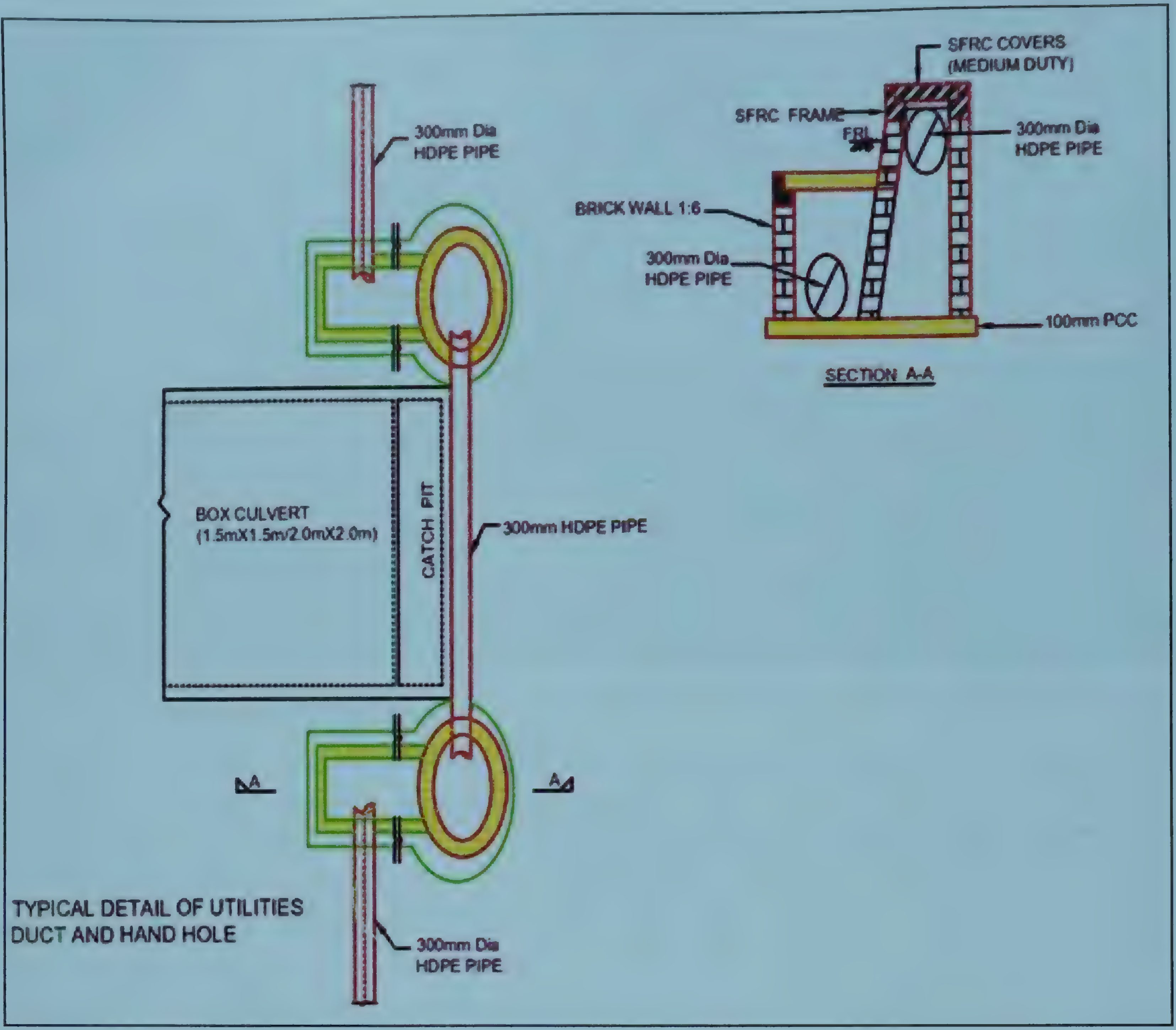

SFRC COVERS
(MEDIUM DUTY)
SFRC FRAME
FRL
300mm Dia
HDPE PIPE
BRICK WALL 1:6
300mm Dia
HDPE PIPE
100mm PCC
SECTION A-A
300mm Dia
HDPE PIPE
BOX CULVERT
(1.5mX1.5m/2.0mX2.0m)
CATCH PIT
300mm HDPE PIPE
A
A
TYPICAL DETAIL OF UTILITIES
DUCT AND HAND HOLE
300mm Dia
HDPE PIPE

Fig. 2.2 (F) Typical Section for crossing the Duct across Precast Box Culvert

(h) IRC-98 “Guidelines on Accommodation of Utility Services on Roads in Urban Areas" and guidelines of Deptt. of Telecommunication, Govt of India and BSNL, issued from time to time may be referred to provide such facility. It is also suggested to get requirement of Cable ducts from the Telecom Operators and incorporate their technical requirements before proposing such facilities.

****

Appendix - 6.1

(Para 6.10)

STEEL FOR CONSTRUCTION OF RAKES/SNOW BRIDGES

Steel is used for compartmentalized snow supporting structures. For supports, girders, and locks, hot-rolled standard profiles are used in most cases. The input values needed to carry out an assessment (e.g. dimensions, section moduli) of standard profiles are taken from tables.

Cold-pressed omega profiles or hat-profiles shall be used as crossbeams. They have a total width of 210 to 242 mm, a width of the upper flange of 58 to 97 mm, and a height of 80 to 100 mm. The inclination of the web is between 10° and 25°. The thickness of metal sheets must between 5 and 10 mm depending upon the span and load requirements.

The steel grade shall confirm to IS 2062 and shall be galvanized and designed for a life of at least 80 years. Fasteners shall confirm to ISO 8992 standards.

Table A I: Minimum requirements of Steel Fabrication

Components	Profile	Dimension	Steel Elements
Girders/Beams	IPE	Min. 140 to 270	IS 2062
Supports/Locks	ROR	Min. 133	IS 2062
	HEA	Min 120	IS 2062
	TPS	Min. 100x100x4	IS 2062
	VHP	Minimum	IS 2062

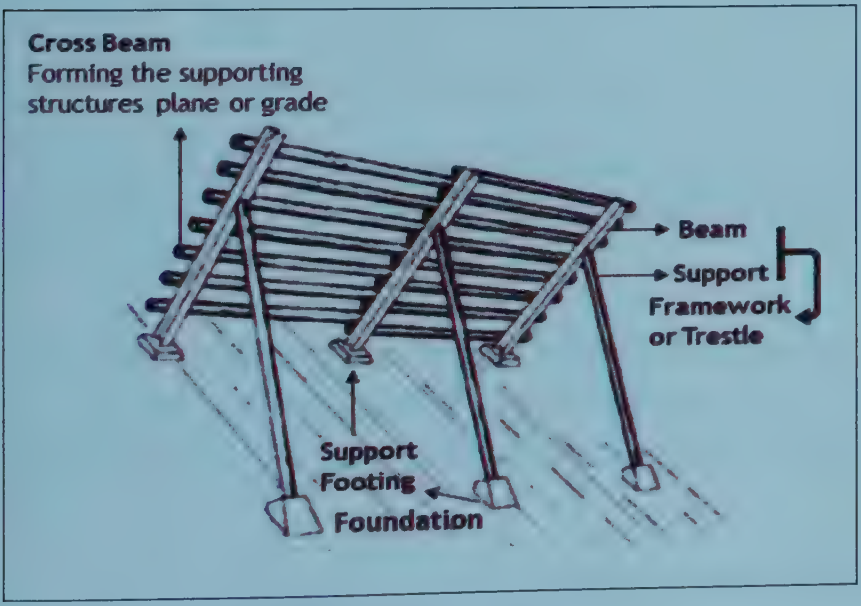

Cross Beam
Forming the supporting structures plane or grade
Beam
Support
Framework or Trestle
Support
Footing
Foundation

Fig. 6.1(A) Representation of Snow Bridge

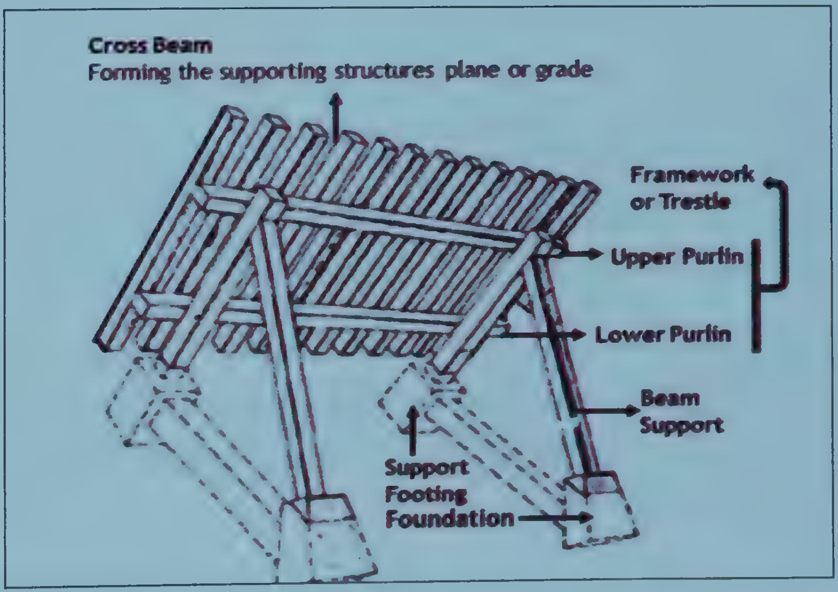

Cross Beam
Forming the supporting structures plane or grade
Framework or Trestle
Upper Purlin
Lower Purlin
Beam
Support
Support
Footing
Foundation

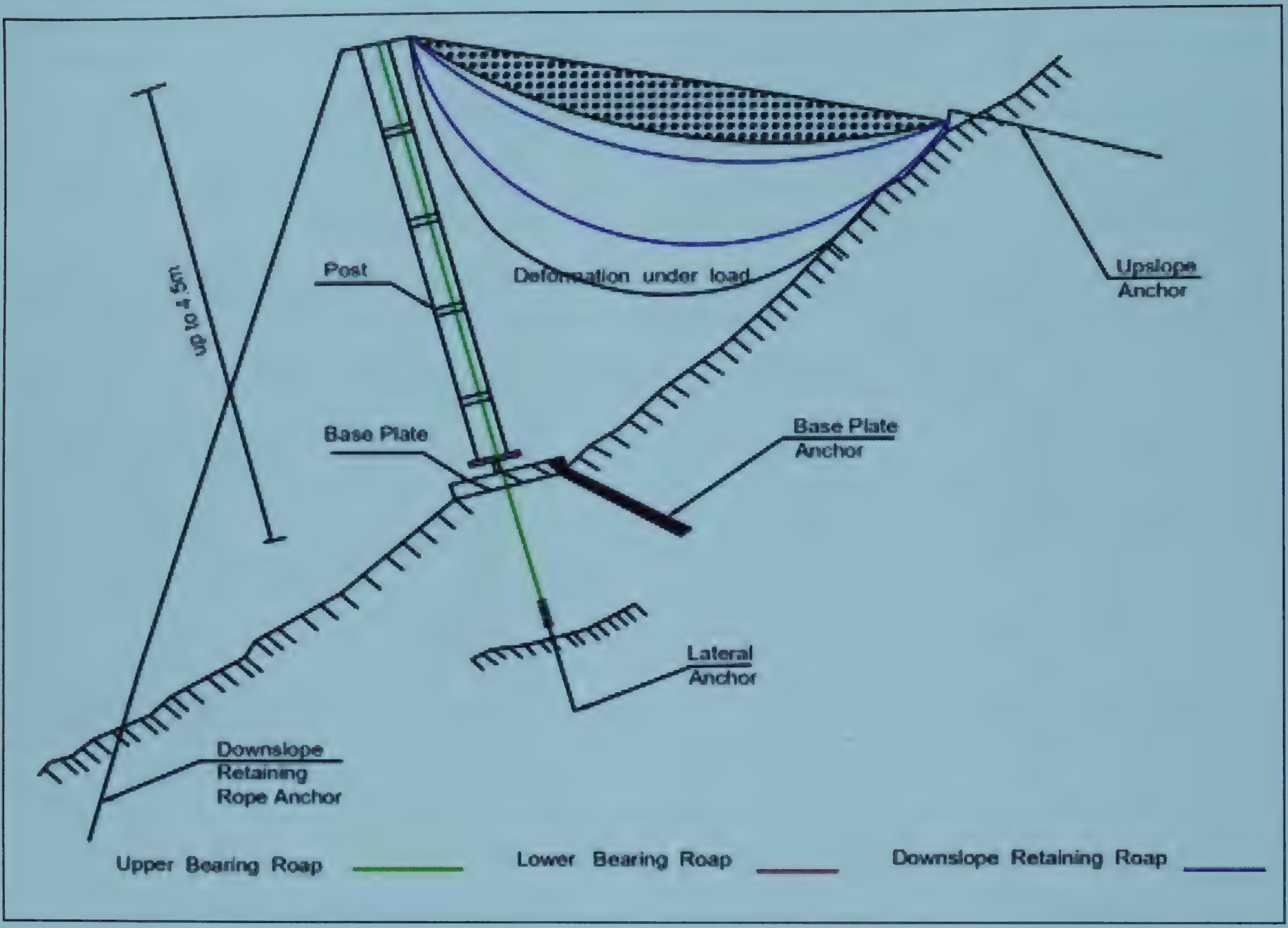
Fig. 6.1(B) Representation of Snow Rake

Appendix - 6.2

(Para 6.10)

GENERAL SPECIFICATION OF MATERIAL IN FORMATION ZONE

Construction Steel for Flexible Nets/ Snow Fences


up to 4.5m
Post
Deformation under load
Upslope Anchor
Base Plate
Base Plate Anchor
Lateral Anchor
Downslope Retaining Rope Anchor
Upper Bearing Roap
Lower Bearing Roap
Downslope Retaining Roap

Snow nets/Snow fences consist of flexible-mounted swivel supports kept downslope with guy wires and upslope with triangular or rectangular, flexible steel cable nets, which are connected to the upslope anchors by connecting cables.

Because of these cable connections, which can be adjusted lengthwise using wire clamps, there is a certain amount of flexibility when choosing the exact position of the upslope and downslope anchor points, which is advantageous under difficult topographical conditions, or when working on creeping soil.

The design value of the service life of permanent supporting structures is 80 years.

Soil Anchors, Micropiles, or SDA anchors must be chosen based on ground conditions and reaction load coming to it. All anchors must be duly galvanized with minimum 85 μm (610 GSM).

Table A: II Basic Construction of Snow Nets

Particulars	**Type of Construction**	**Corrosion Protection**
Primary Mesh	Cable Ropes	Zn+Al
Secondary Mesh	Wire mesh	Zn, Zn+Al (Class A or B)
Posts	HEA/ HEB	Zn
Base Plates	IS 2062	Zn, Zn+Al (Class A or B)
Fasteners/Shackles etc.	ISO 8992	Zn, Zn+Al
Ropes	1770N/mm^2	Zn+Al (Class A or B)

** All parts must be galvanized as per EN 10224-2, EN 10327, base plates as EN per ISO 1461 requirements.

The following guidelines may be referred for detailed design, specifications and dimensioning of snow nets, snow rakes, snow fences etc.

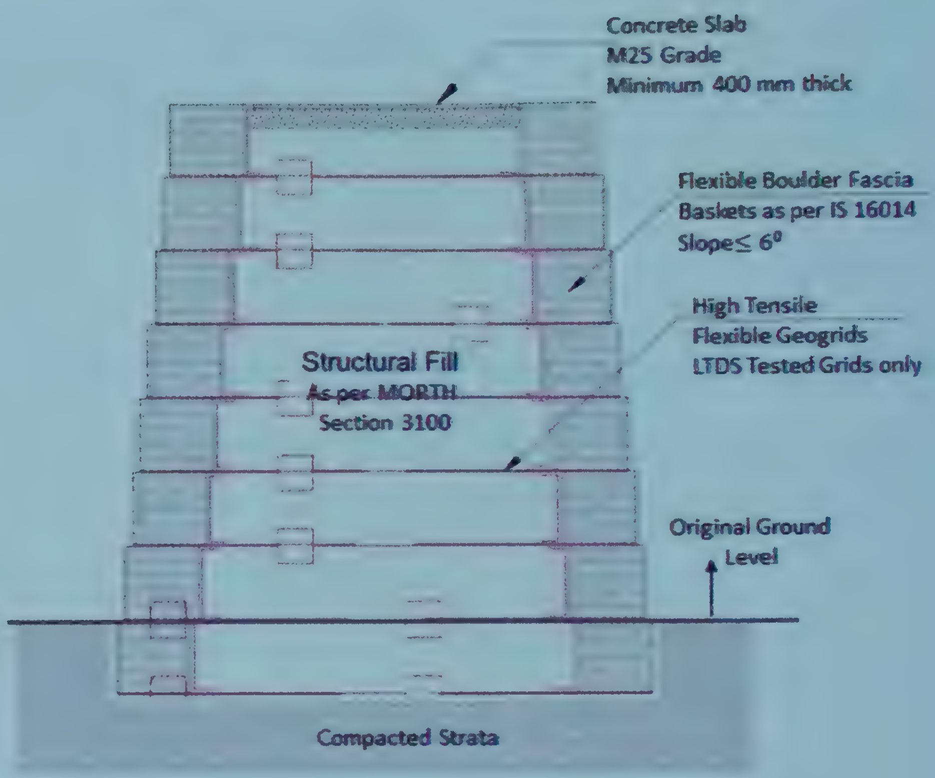
1. Austrian Standards Institute. *ONR 24806,* Permanent Technical Avalanche Protection - Design of Structures, 2011.
2. WSL Swiss Federal Institute for Snow and Avalanche Research SLF. Defence structures in avalanche starting zones - Technical guideline as an aid to enforcement, 2007

Appendix - 6.3

(Para 6.10)

GENERAL SPECIFICATION OF MATERIAL IN MIDDLE/RUN-OUT ZONE

Construction of Flexible Structures for Catch Dam/Deflectors/Splitters/Blast Walls



The structure is designed using the principles described in BS 8006:2010. This is a limit state procedure considering both ultimate and serviceability limit states. Additionally, FHWA and AFNOR, IS 1893 (or their latest revision) Guidelines shall be considered for seismicity.

Partial load factors greater than unity are applied to the nominal loads having disturbing effects. Design material properties are calculated by dividing the characteristic properties by the appropriate partial resistance factor.

The ultimate limit state considers the factor of safety against collapse and the serviceability limit state considers the magnitude of deformation that will occur during the service life of the structure. The ultimate limit state assessment considers both the external and internal stability of the structure.

Most importantly, such structures offer, at low relative cost, an ideal material for sustaining dynamic loads. This is well known for example in Japan, where similar structures have been widely used based on the outstanding seismic performance, even under the most severe earthquake motions (Otani, 2013). But it is also the case for dynamic impacts, distributed like avalanche or explosion blasts, or localised in the case of rock falls. It is also important for avalanche loads since the snow flow is likely to bring other debris which will hit the dam or the braking mounds, like rocks or trees. The localised impacting energy is absorbed by moderate localised internal deformation of the granular fill. The localised impacting energy is absorbed by moderate localised internal deformation of the granular fill.

Fill Materials

The core fill within the reinforced zone may be a blasted or crushed rock having a bulk density of 20 kN/m^3 or above and a characteristic angle of internal friction > 30°. The general fill forming the rear face shall have a minimum bulk density of 20 kN/m^3 and a characteristic angle of internal friction of 30°.

The structure shall be constructed on a compacted ground, and at above a minimum 2.00 m deep sub-fill layer having the same properties as the core fill within the reinforced zone. For, requirement of properties of fill material, reference shall be made to MoRTH Section 3100.

Facing

MoRTH Section 3100, Metallic Facing, Prefabricated in different shapes including welded wire grid, steel sheet and woven steel wire mesh, where steel sheet and steel grid facings are used for facing, steel for steel sheet shall be as per BS:1449-Part1 and steel grids shall confirm to BS:4482, BS:4483 and BS:4489

Soil Reinforcement

The reinforcement element enhances the stability of the reinforced fill mass by mobilizing the axial tensile strength of the fill reinforcement by soil interaction over its total length. It is typically a tension element made of steel or polymer in the form of a steel strips, strap, high adherence straps, shall be placed in discrete layers as per MoRTH 3100.

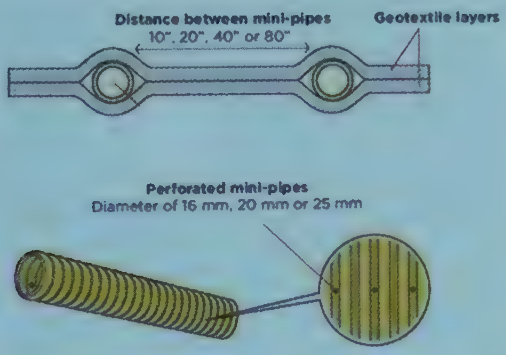
Any type of steel or geosynthetic material used as reinforcing element for the construction of a reinforced slope shall meet all the requirements provided in the relevant clause of MORTH Section 3100.

Drainage Arrangement

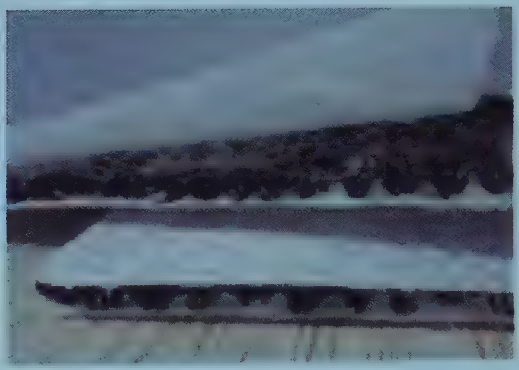
The drainage arrangements at the bottom or intermediate drainage arrangements shall consist of the following.

Cross-Drainage: Semi-perforated PVC Pipe Wrapped with needle punched polypropylene geotextile

Sub-surface Drainage: Sub-surface drainage shall be of geocomposite of similar configuration as shown in the representative image.


Distance between mini-pipes
10", 20", 40" or 80"
Geotextile layers
Perforated mini-pipes
Diameter of 16 mm, 20 mm or 25 mm

Type 1



Type 2

Type 1 : For Structures in inundated condition

The drain tube geocomposite consists of:

- A non-woven filter layer on the upper part
- A non-woven draining layer with mini pipes regularly perforated according to a 90° dual alternated axis
- A non-woven filter layer on the lower part.

Type 2 : For Structures in Wet/moderately dry/ dry condition

These Composites are made up by associating, during production, a draining core layer (extruded monofilaments set in longitudinal parallel channel configuration) between two layers of geotextiles. The composite is capable of providing either filtering, separation and, sometimes, also other functions such as protection.

The long term draining performances of the composite must be well known (compressive creep, flowarate variations, filter efficiency etc.).

All the components shall be of in polypropylene.

Components must be joined or fused together by needle-punching to avoid any change in their mechanic and hydraulic characteristics described below.

Connections between fascia system and soil reinforcing elements

Since, avalanche dams are located in high seismic zone, the connection systems is of importance during as it has to sustain the seismic movements and avalanche impact loads during initial events. The deformation of the face must be restricted using a robust positive connection system. BS 8006: 2010, Annexure F (Design of reinforced soil structures for earthquake resistance), guidelines to connection system in seismic locations must be adopted.

Reinforced soil structures with steep or vertical faces provide a number of advantages for the construction of avalanche protective barriers of all kinds: braking mounds, deflecting dams and catching dams. Similar structure located in Iceland proved to be a very good example of the versatility of the solution and of its integration within the local environment.

Further Reference: For other design parameters used for catch Dam/deflectors/splitters design, a publication by European Commission referred “The design of avalanche protection dams” (Recent practical and theoretical developments) may be referred.

Appendix - 6.4

(Para 6.10)

PRE-CAST RCC ARCHES FOR AVALANCHE DEFENCE

Precast Hinged RCC Arches shall be proposed for cut and cover sections for avalanche protection system based on their distinct advantages over the conventional cast -in-situ cut and cover box section especially in the high altitudes.

These advantages are based on the time constraints, ease of erection, short working seasons and extreme weather condition for casting of concrete. These RCC precast arches shall form a three-hinged arch structure. The hinge points shall be at the crown of the arch and the bottom of the arch.

Geometry

The geometry and loading on the segmental arch shall be evaluated with a fill and cushion of minimum 2.00 m above the surface including the depth of overburden and but excluding the height of avalanche deposit. The selection of the appropriate shape shall be based on finite element modelling, which shall be aimed to minimize the tensile forces in the arch shape, thus creating an axially loaded structure. This shall be achieved by evaluating the arch as a funicular curve.

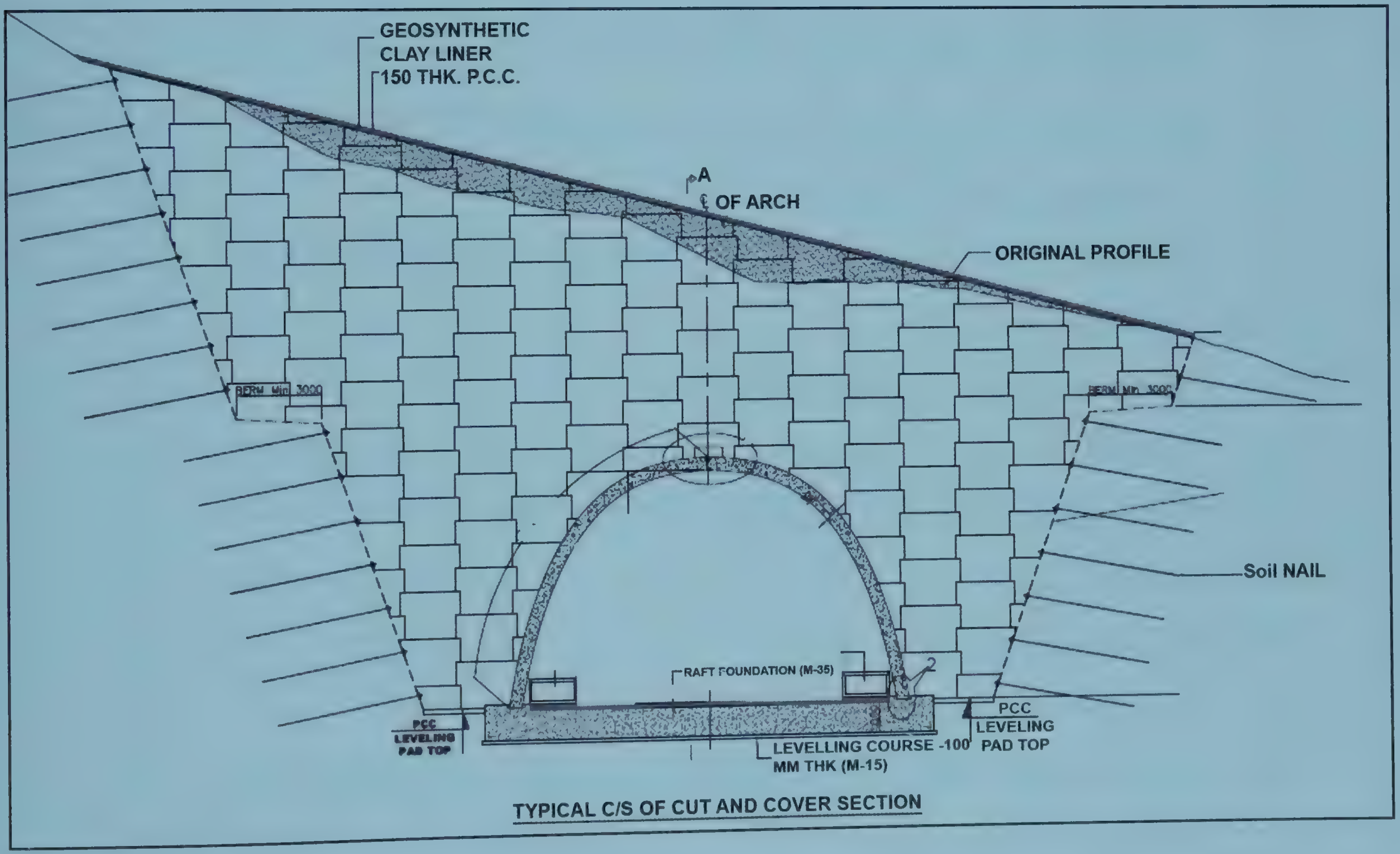

GEOSYNTHETIC
CLAY LINER
150 THK. P.C.C.
A
℄ OF ARCH
ORIGINAL PROFILE
BERM Min 3000
BERM Min 3000
Soil NAIL
2
RAFT FOUNDATION (M-35)
PCC
LEVELING
PAD TOP
LEVELLING COURSE -100
MM THK (M-15)
PCC
LEVELING
PAD TOP
TYPICAL C/S OF CUT AND COVER SECTION

Fig. 6.4(A) Typical Representation of Pre-cast Cut and Cover Section for Avalanche Defence

Appendix-8.1

(Para 8.5.1.2)

CHECK LIST OF POINTS TO BE EXAMINED DURING INSPECTION FOR MAINTENANCE OF HILL ROADS (AT LEVEL OF ASSISTANT ENGINEER/JUNIOR ENGINEERS/SUPERVISOR)

1. **Safety Aspects**
   - (a) Safety precautions of slides/slips, breaches, blockades
   - (b) Deep cuts on road
   - (c) Damaged Culverts/Bridges
   - (d) Horizontal and vertical clearance of power lines crossing the road.
   - (e) Branches of trees with low height obstructing vertical clearance
   - (f) Proper signage as per IRC:67
   - (g) Road Marking as per IRC:35
2. **Land-slide/Unstable Areas**
   - (a) Behavior of the slide whether dormant, active or unstable areas likely to become active any movements observed
   - (b) Effectiveness of control measures already done
   - (c) Functioning of drainage arrangement
   - (d) Condition of protective/control structures and their effectiveness
3. **Snow-fall/Damages**
   - (a) Advance action required for snow clearance
   - (b) Condition of snow/avalanche control structures-repair required
   - (c) Additional control measures required
   - (d) Snow fall pattern
4. **Roads Profile and Section**
   - (a) Condition of slopes on hill and valley side
   - (b) Requirement of retaining/protective structures to retain/correct slope
   - (c) Easing of slopes required
5. **Carriageway and Crust Conditions**
   - (a) Magnitude and location of potholes
   - (b) Condition of edges

(c) Magnitude and location of undulations

(d) Location of crust failures along with their causes

(e) Condition of camber/cross-fall/super elevation, whether affected by subsidence, etc.

6. **Shoulders (Berms) and Embankment**

(a) Width of berm adequate as per specification or not

(b) Cross slope of bems-check if correct.

(c) Magnitude and location of undulations

(d) Location of crust failures alongwith their causes

(e) Condition of camber/cross-fall/supper elevation, whether affected by subsidence, etc.

7. **Drainage (Side, Catch Water etc.)**

(a) Cross sectional area adequate or not

(b) Blockage/damage to drains

(c) Flow in drain and disposal of discharge

(d) Bed slopes, lining etc- are they in good order or to be rectified

8. **Culverts/Scuppers/Minor Bridges**

(a) Damages, if any

(b) Free flowing is there any blockage

(c) Silting of catch-pits

(d) Damages to head walls, parapets etc, if any

(e) Damages to chutes, guides

9. **Protection Works (Retaining Walls, Breast Walls, Parapets, Aprons, etc.)**

(a) General condition

(b) Any damages/cracks

(c) Weep-holes- effective functioning

(d) Apron, revetment, pitching-properly maintained or not.

10. **Road Furniture**

(a) KM stones, boundary stones exists in proper condition.

(b) Traffic sign correctly located and maintained.

(c) Painting and numbering of culverts, bridges and structures.

11. Toll Plaza / Traffic Aid Post / Emergency Medical Services and Communication Systems

(a) All the component of Toll plaza including function of RFID reader

(b) Waiting time at Toll Plaza

(c) Functioning of Traffic Aid Post / Medical Aid Post

(d) Functioning of all communication systems provided on the stretch

12. Roadside Arboriculture

(a) Check if numbering of trees is done or not

(b) Disposal of dead trees

(c) Register of trees maintained

(d) Planting of new trees being done or not as required

(e) Location & condition of drums/parapet wall/guardstones on curves.

13. Road Geometrics

(a) Sight distance and obstruction, if any

(b) Improvements required in horizontal curves, like layout, extra width etc.

(c) Vertical Curves-Check visibility and obstruction, if any

(d) Passing places- are they in good shape and being used as expected-is its location correct.

14. Roadside Material

Whether aggregates, bitumen, required for maintenance are available at sites, located at regular interval and are stacked properly.

15. Encroachment

Encroachment, if any to be checked and action for their removal

Appendix-10.1

(Para 10.18.3.6)

ROAD SAFETY SLOGANS

1. Any time is safety time.
2. Safe driving is more HORSE SENSE than HORSEPOWER.
3. Safety is everyone's business – including YOU.
4. Safety! Make it a habit.
5. Kindness is giving the Right of way.
6. Safety is checking before moving.
7. Leave early, drive slowly, Arrive safely.
8. Wish you a happy and safe journey.
9. Mountains are a pleasure only if you drive with leisure.
10. Driving with care make accidents rare.
11. Be soft on the Curves.
12. Speed thrills but kills.
13. Be cautious on Curves.
14. Remember always what I narrate, Do not unnecessarily accelerate.
15. Life is secured in limited speed.
16. Live for your today. Drive for your tomorrow.
17. Drive slower, Live longer.
18. Self-confidence is the first requisite to great undertakings.
19. Hard work is the best investment a man can make.
20. Our self-made men are the glory of our institutions.
21. Let another man praise thee, and not thine own mouth.
22. Self-trust is the essence of heroism.
23. East or West, Home is the Best.
24. First deserve, then desire.
25. We built Road for your Development
26. Help us to serve you better
27. Donate Blood but do not waste it on the road.

28. We cut mountains to connect hearts.
29. The safe way is the right way.
30. Hug your kids at Home. But Belt them in the car.
31. Your safety is our Success.
32. If you are married Divorce Speed.
33. It is better to be Mr late than Late Mr.
34. It is better to loose a minute than to loose a life.
35. Driving faster cause Disaster.
36. Road is Hilly Do not Drive Silly.
37. Start Early, Drive Slowly, Reach Safely
38. Enjoy the Beauty of Valley.
39. Drive Slower, Live Longer.
40. Lane Driving is Safe Driving.
41. Peep Peep Don't Sleep.
42. Road Signs are the Sign of Life.
43. Keep smiling while driving
44. I am Curvaceous, Be Slow.
45. Horn is the Honk please do it on curves.
46. Go slow on curves.
47. Keep your nerves on the sharp curves.
48. On the Bends, Drive slow friends.
49. After Drinking Whisky,Driving is Risky.
50. Drive on Horse Power, Not on Liquor Power.
51. Never Drink and Drive on Hills.
52. Three enemies are on the road, Liquor, Speed and Overload.
53. For Safer Arriving no Liquor in Driving.
54. Enjoy the Charming Nature around you.
55. Dear I like you but not your Speed.
56. Do not Gossip, Let him Drive.
57. Dear I will listen you, let us reach Home.
58.. Safety on Road is Safe at Home.

59. Love the Neighbour but not while Driving.
60. Drive Carefully, Live Cheerfully.
61. Drive, don’t fly.
62. It is not a Runway, it is just a Highway.
63. No Race, No Rally, drive slowly
64. It is not Rally or Race, but Drive with Grace.
65. Do not unnecessarily Accelerate.
66. Over speed is Knife that Cuts a Life.
67. Let your Insurance Policy Mature before you.
68. A cat has Nine lives but not the one who Drives.
69. Driving and Day Dreaming, Do not go together.
70. Alert, Avoid, Accident.
71. Accident Begins when Alertness ends.
72. Safety is checking before Moving.
73. Keep your Cool.
74. A wise man Drives Safely.
75. Enjoy the Scenery, Protect the Greenery.
76. Divided Attention leads to Multiple Troubles.
77. Do not be Gama, In the Land of Lama.

Appendix - 12.1

(Para 12.17)

DO'S & DON'TS ON THE USE OF EXPLOSIVES

a) General

i) **Don't** Smoke or have matches, naked light, etc. while storing, transporting, or using explosives,

ii) **Do** Store explosives in dry, clean and well ventilated magazine. Separate persons should carry explosives and detonators while transporting these to the blasting site.

iii) **Don't** Keep explosives and detonators in the same box or the same magazine Separate persons should carry explosives and detonators while transporting these to the blasting site.

b) While Using

i) **Don't** Use tools made of iron or steel for opening cases. Use hard word or brass implements.

ii) **Don't** Leave explosives lying in the hot sun.

iii) **Do** Replace the cover of the case after the required quantity has been taken out.

iv) **Don't** Carry explosives in your pockets

v) **Don't** make up primers near large stacks of explosives

vi) **Don't** insert anything but a fuse inside a detonator

vii) **Don't** handle or be near explosives during an electric storm. All persons should retire to a place of safety.

viii) **Don't** use damaged or deteriorated explosives and accessories.

ix) **Don't** break explosives cartridge

c) While Drilling and Charging

i) **Don‘t** Start drilling until you have made sure that the rock face contains no unfired explosives. Never drill into explosives.

ii) **Do** check condition of shot hole with stemming rod before inserting detonating fuse.

iii) **Don't** Force detonating fuse into a hole.

iv) **Don't** keep large unwanted stocks of explosive near the shot holes.

v) **Do** cut detonating fuse from the reel immediately after the primer has reached the bottom of the hole.

vi) **Don't** try to soften cartridge or hardened explosive by hitting or by rolling on the ground.

d) **While Stemming**

i) **Don't** use metallic rods for stemming. Use only wooden rods. The end of the rod should be kept squire by sawing off the pointed end periodically.

ii) **Don't** apply pressure directly on the primer cartridge. Always put a few cm of stemming after the primer is in position inside the hole.

iii) **Don't** use sharp particles in the stemming

iv) **Don't** damage fuse, lead wires or detonating fuse while stemming.

e) **While Firing with safety Fuse**

i) **Don't** use short fuse. The minimum length should be 1.2m and make sure you have time to reach a place of safety before the explosive detonates.

ii) **Do** use only approved crimpers for securing detonators on to fuse.

iii) **Do** use fuse lighters. If matches have to be used slit the end of fuse, hold the match head in the slit and rub the side of an empty match box against the match-head

iv) **Don't** use explosive cartridges for lightering fuse. It is extremely dangerous.

f) **While Firing Electrically**

i) **Don't** use electric detonators during dust storms or near any other source of large static charges.

ii) **Do** keep the firing circuit insulated from the ground, bare wires, ralls, pipes or any other paths of stray currents.

iii) **Do** test the firing circuit with an Ohmmeter or circuit tester from the firing

iv) **Do** make sure that all joints are firm, clean and dry.

v) **Do** keep lead wires short-circulted until ready for firing.

g) **Before and After Firing**

i) **Don't** fire until you have made sure that all surplus explosives have been removed and all persons, vehicles and equipment are at a safe distance.

ii) **Don't** return to the blasting site soon after misfire. Wait five minutes when firing electrically or wait 30 minutes if firing with safety fuse.

iii) **Do** handle misfires with care.

Appendix - 13.1

(Para 13.8.1)

IMPORTANT POINTS ON WHICH ATTENTION IS REQUIRED DURING PLANNING, CONSTRUCTION AND MAINTENANCE OF HILL ROADS

1. Any road construction activity in the Hilly region should be based on a Master Plan of the district and should be integrated with existing roads as far as possible.

2. It may not be possible to give road connections to all villages. The concept of giving connection to a cluster of villages though an all-weather motorable road is more practicable. The other villages could be connected to the roadhead through bridle paths, bridle bridges, foot tracks or light vehicle roads as feasible.

3. All road construction activities should be coordinated through a single agency both at the central and the state level.

4. Roads to be constructed by all agencies should generally conform to the design standards and specification laid down by IRC for similar category of roads.

5. Adequate attention must be paid while selecting road alignment, that landslide/erosion prone areas are avoided as far as possible. While selecting the road alignment the advice of geotechnical engineers and geologists, forest and soil conservation experts should be taken right from the start.

6. During process of road construction, cut and fill method should be resorted to in order to cause minimum disturbance.

7. Heavy rock blasting should be avoided and controlled blasting should be resorted to by using a low explosive charge. Blasting should be adequately supervised by technical personnel. Selection of blasting holes should be so done as to avoid large scale disturbance to the rock face, developing cleavage planes/cracks and opening up fissures etc.

8. Spoil from cut/blasted rock should not be thrown haphazardly along the valley slopes as these are likely to cause heavy siltation/chokage of water channels/streams and damage agricultural lands. These should be preserved by stocking at selected location along roadside for future use.

9. Cut slopes should be rendered stable in the construction stage itself by cutting at the correct angle and benching etc. including slope stabilizing structures like drains, breast walls, pitching etc. Wherever considered appropriate on the basis of a technical study conducted for the purpose, funds should be provided in the project estimates for the treatment of the unstable areas both above roads level and below road formation. Steps should be taken to stabilize the existing roads within a fixed time frame.

10. All cut/denuded slopes should be treated with vegetative turfing.

11. Deforestation during the construction of road should be kept to the minimum and should

be done only in consultation with forest authorities. Any cutting of trees must be replaced by planting 3 to 4 times the number so that atleast an equal number survives.

12. Drainage of water from roadside should be given adequate attention and an effective system of drainage should be constructed to lead the run-off to natural water courses. In particular, suitable intercepting and catch water drains should be provided above the cut slopes for the speedy and safe disposal of water. It should be ensured that water is not drained into villages and cultivated land. Location of cross drains and culverts should be so chosen as to avoid erosion of the outlet. Adequate erosion control works like drop walls, apron etc. at out-fall points alongwith pitching/paving of the channel should be undertaken.

13. To minimize the adverse effects of cattle grazing proper check should be exercised and the concept of rotational grazing should be implemented. 'Jhoom' cultivation, impounding water very near and above the hill roads for terraced paddy cultivation and fish rearing must be avoided.

14. The use of horizontal drains represents the most promising method of correcting flow types of landslides. Efforts should be made to install horizontal drains at selected locations with a view to gaining first-hand experience of their functioning and in order to develop their use.

15. The main approach to the control of rock-fall should be to contain the rock-fall deflect the falling rock away from the road pavement and towards the cliff.

16. To the extent the feasible, road should be aligned away from streams and torrents except where these are to be crossed. Since the greatest damage always occurs along water courses, special attention is necessary to create protection belts of forests on both sides.

17. Excavated material should not be thrown haphazardly but dumped duly dressed in a suitable format suitable places where it cannot get easily washed away by rain and such spoil deposits may be duly turfed or provided some vegetative cover towards the same purpose.

18. Strip forests with suitable site condition for minimum distance of 30 m on either side of the road should be provided. These should be raised and maintained by forest authorities. No felling except of dead or dying trees should be permitted in this area.

19. A mountainous road, when located along a river valley, has the inherent advantage of gentle gradients, proximity to in-habited village, and general convenience of construction and operation of the facility. However, this solution has the disadvantage of large outlay on cross drainage and protective works as well as problem of erosion. All these factors should be carefully considered before making final selection.

20. The alignment should involve least number of hairpin bends. Where unavoidable, these should be located on stable and less steep slopes.

21. While locating roads in high mountain ranges, it may be expedient and economical in some cases to construct tunnels to shorten the length of the alignment.

22. As far as possible, mountain ridges should be crossed at their lower elevation.

23. In hilly country, a location subject to sunlight should get preference over a location in the shade. In snowfall area roads should run, as far as possible on southern face of hill to get sun light for maximum period in winter.

24. Areas liable to snow drift should be avoided.

25. Prompt removal of debris blocking the road because landslides or other reasons.

26. Eroded areas should be promptly made up and provided with vegetative cover.

27. Drains, catch pits etc., should be cleared of all debris and repaired where necessary before the onset of the rainy season.

Appendix - 13.2

(Para 13.8.1)

CHECK LIST OF POINTS ABOUT EROSION CONTROL ON THE CONSTRUCTION OF ROADS IN HILLY AREAS

1. Does the road construction project estimate provide for necessary measures against soil erosion.
2. Have soil maps and aerial photographs studies and investigations been made to locate areas or sections with high erosion potential.
3. Has erosion potential been considered for each alignment.
4. Have geological maps been studied or local geological department consulted to avoid unstable strata.
5. Does the selected alignment follow the lie of the land and avoid large scale cutting.
6. Has use of tunnels to avoid deep cuts been investigated.
7. Is the road alignment suspect to damages/erosion by streams and torrents.
8. Is Consultation/coordination with other departments like forest department necessary. If so, have they been consulted.
9. How will adjacent and nearby streams, ponds and taken be affected by project construction.
10. Does the road cross section involve a lot of disturbance to the natural ground.
11. Are the design cut slopes sable for the type of strata.
12. Are slope stabilizing structures like breast walls, pitching etc. required.
13. Does the cut hill face require any special treatment to prevent slips.
14. Has the area for clearing and grubbing been clearly demarcated.
15. Has a work schedule been worked out for the different construction operations.
16. What erosion control works are required before clearing and other works are started.
17. Are any temporary erosion control measures required between successive construction stages.
18. Have sediment traps, benches, catch water drains, slide drains, ditch paving, slope protection works and other erosion control items been identified on the plans and provided in the proposals.
19. Have the location and alignment of culverts been fixed with due consideration to erosion at outlets and siltation at inlets.
20. Have the necessary erosion control measures been taken at the out falls of culverts.
21. Has the proper disposal of surplus excavated material been throught of and provided for.
22. What action has been taken to establish vegetative cover to cut/fill sloes and plantings on the disturbed roadside land.
23. Are the existing drainage facilities maintained in good order.
24. Do any of the design measures required modification in the light of field conditions.

(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the Code/Guidelines/Manual, etc. from the date specified therein)

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